Historic, archived document

Do not assume content reflects current scientific knowledge, policies, or practices.

Has been rev.
--see rev.ed.
binders at
end of file.

LIBRARY
BUREAU OF
FEB 20 1936
AGRICULTURAL
U. S. DEPARTMENT OF AGRICULTURE

CIRCULAR No. 369 DECEMBER 1935
UNITED STATES DEPARTMENT OF AGRICULTURE
WASHINGTON, D.C.

INDUSTRIAL FUMIGATION AGAINST INSECTS[1]

By E. A. Back, *principal entomologist*, and R. T. Cotton, *senior entomologist*, *Bureau of Entomology and Plant Quarantine*

CONTENTS

	Page
Introduction	1
General mill or warehouse fumigation	2
Requirements for a successful fumigation	5
Preparing the building for fumigation	6
Desirability of a high temperature during the fumigation	8
Effect of wind velocity	9
Choice of a fumigant	9
Quantity of fumigant needed	9
Applying the fumigant	10
Fumigation with hydrocyanic acid gas	11
The barrel or pot method	11
The liquid method	17
The discoid method	20
The powder method	23
Fumigation with chloropicrin	24
Fumigation with ethylene oxide-carbon dioxide mixture	25
Fumigation with methyl formate-carbon dioxide mixtures	26
Vault fumigation	27
Use of fumigants suitable also for large spaces	30
Use of other fumigants	30
Carbon disulphide	30
Carbon tetrachloride	31
Ethylene dichloride	31
Ethylene oxide	32
Bin fumigation	32
Vacuum fumigation	33
Equipment	33
Procedure	35
Fumigation of various commodities	37
Fumigation of various commodities—Contd.	
Confectionery	38
Vault fumigation for nuts	38
Vacuum fumigation for nut meats	38
Fumigation schedule for candy factories	39
Dosages	39
Furniture	39
Furs and garments	40
Construction of storage rooms	40
Dosages	40
Effect of fumigation on furs	42
Rugs and tapestries	42
Dried fruit	43
Treating the finished product	44
Infestations in warehouses	44
Cured meats and cheeses	45
Stored tobacco	45
Flour	47
Preparing the mill for fumigation	47
Choice of fumigant	48
Hydrocyanic acid gas for mill fumigation	48
Chloropicrin as a mill fumigant	48
Local fumigation	49
Fumigation of flour warehouses	49
Vault fumigation for flour or cereal mill	49
Safeguards to be employed in fumigation work	50
First aid for poisoning from hydrocyanic acid gas	51
Shaefer prone-pressure method of artificial respiration	52

INTRODUCTION

Insect infestation is frequently a problem of considerable importance in the storage of many types of merchandise. During warm weather or in heated buildings, foodstuffs, cereals, seeds, tobacco, furs, fabrics, etc., are highly susceptible to infestation by insects, and heavy losses are likely to occur unless adequate protection is given them. If cold-storage facilities are available, such commodities can be protected from insect damage by holding them at temperatures below 45° to 50° F Many times, however, it is impossible or

[1] The investigations upon which this circular is based were made in the former Division of Household and Stored Product Insects, and the manuscript was prepared and submitted by that Division.

impractical to use cold storage, and it is necessary to resort to fumigation. This circular describes various methods by which products in storage or the establishments in which they are manufactured can be protected from insect attack by the use of fumigants.

In the protection of stored commodities four methods of fumigation are in common use: (1) The general or large-scale fumigation of warehouses and mills (fig. 1), (2) vault fumigation (fig. 2), (3) bin fumigation (fig. 3), and (4) vacuum fumigation (fig. 4). Each method is adapted to a certain type of work and will be discussed separately. In most industries a combination of two or more

FIGURE 1.—Interior view in flour mill ready for fumigation with hydrocyanic acid gas generated by the barrel method. The eight barrels containing the acid-water mixture stand in galvanized-iron washtubs, and a sack of sodium cyanide is ready to be lowered into each barrel.

of these methods can be used to advantage; and sometimes special methods, such as fumigation under tarpaulins (fig. 5) or the treatment of the individual pack of a commodity (fig. 6), are developed.

GENERAL MILL OR WAREHOUSE FUMIGATION

All mills, factories, warehouses, and storage rooms in which material subject to insect attack is handled become infested at one time or another and need a general fumigation. The managers of many such places realize the importance of maintaining a clean plant and fumigate one or more times a year as a general practice. Others, fearing the trouble and expense, wait until conditions become so bad that they are forced to shut down their mills for a thorough cleaning and fumigation.

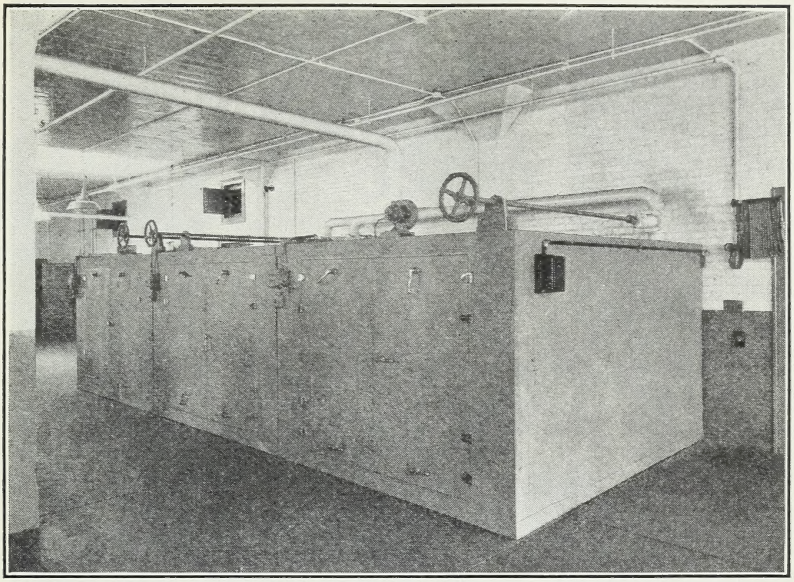

FIGURE 2.—A battery of three modern steel fumigation vaults, each about 6 by 8 by 10 feet, equipped with apparatus for introducing and withdrawing the fumigant, and for heating and circulating the air within. Such vaults are used for treatment of various commodities, in this instance furs, and not ordinarily for continuous storage.

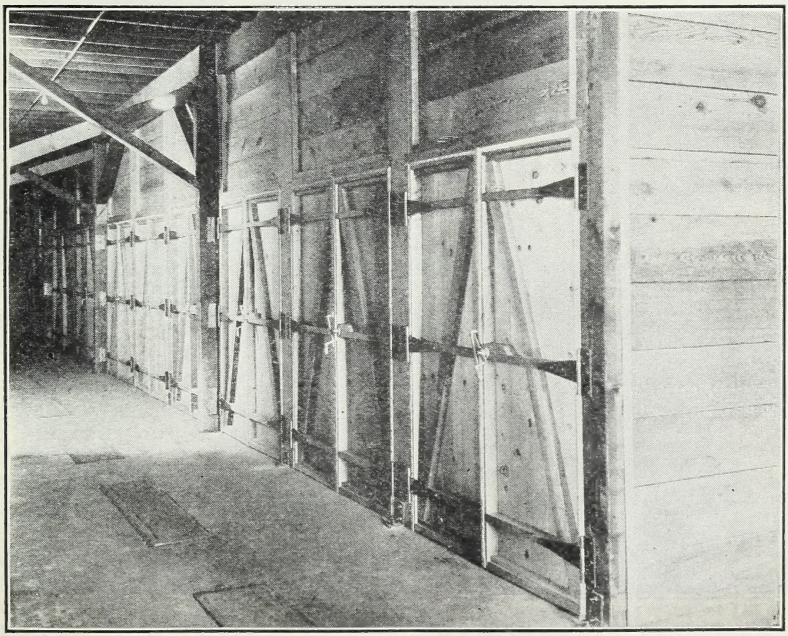

FIGURE 3.—A battery of 10 storage bins so constructed that dried-fruit products stored in them can be fumigated.

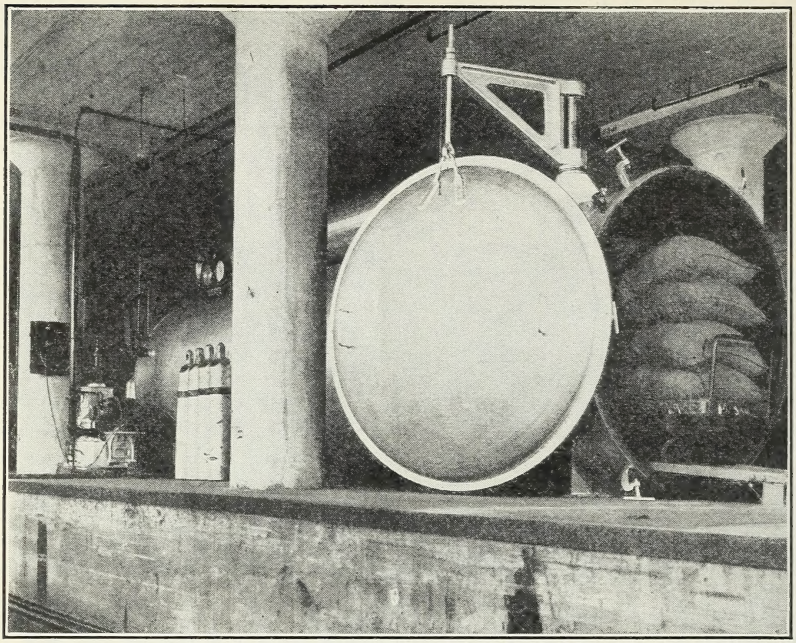

FIGURE 4.—A vacuum fumigating unit in a large general-merchandise storage warehouse. Since it is located along the railroad siding, susceptible commodities are fumigated as they are unloaded from the freight car and before they are placed in storage rooms, where only fumigated supplies are stored.

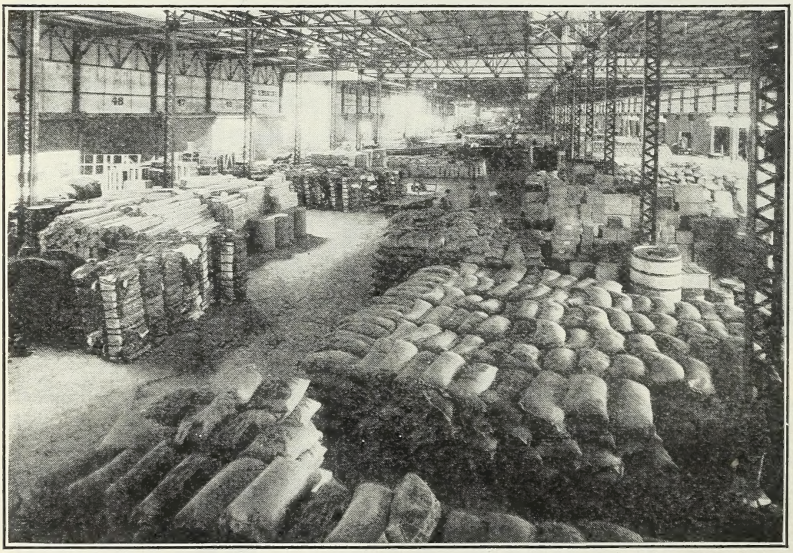

FIGURE 5.—Commodities of various types assembled for export on a modern dock. Carload lots of supplies found slightly infested upon arrival by rail are sometimes fumigated beneath rubberized tarpaulins. While such treatments are not always entirely satisfactory, they are resorted to in numerous instances.

There is no reason why fumigation should be an expensive operation, for with a simple equipment a few intelligent workers can be quickly trained to fumigate most places with no more expense than their time and the bare cost of the materials.

REQUIREMENTS FOR A SUCCESSFUL FUMIGATION

Success in the fumigation of any large building or enclosure depends upon the proper planning and execution of the work, the careful preparation of the building, and the correct choice of the fumigant and time of its application. The building must be made as nearly gastight as possible in order to avoid waste of gas and to retain a lethal concentration of the fumigant as long as possible.

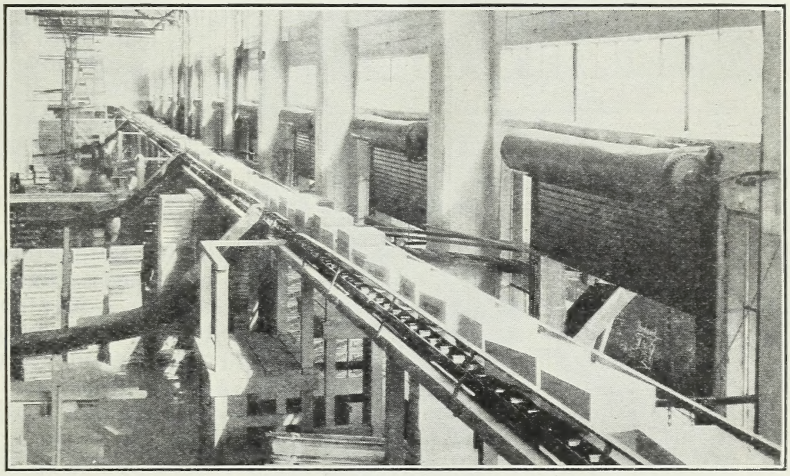

FIGURE 6.—While industry in general has not found it feasible to promote insect sanitation by introducing a fumigant into the shipping unit as it moves through the packing machinery, this is a method that has been satisfactorily employed. The fumigant, in liquid form, is automatically introduced in each container just previous to the entry of the commodity and the sealing of the container.

All machinery or special pieces of apparatus must be cleaned and opened up to allow maximum penetration of the gas.

The temperature must be high enough to render the insects susceptible to the fumigant and to allow for its most efficient action.

The fumigant must be suitable for the building in which it is used and for the contents of the building. The quantity must be great enough to allow for the loss through poor construction of the building, absorption by the contents of the building, and adverse weather conditions. The fumigant must also be properly applied and distributed. The exposure must be long enough to permit maximum penetration and killing effect.

Precautions must be taken to see that all persons are out of the building before the fumigation is started, and are kept out during the fumigation and thereafter until the building has been properly ventilated and declared safe to enter. Arrangements should be made for quickly ventilating the building at the end of the fumigation.

PREPARING THE BUILDING FOR FUMIGATION

It is essential that the building be made as nearly gastight as possible. A modern concrete building having windows with steel frames is excellent for fumigation purposes, since little effort is needed to make it reasonably gastight. Doors leading to the outside should be sealed (fig. 7). Ventilators on the roof (fig. 8) or outside walls should also be sealed over, and any windows that are not tight should be sealed around the edges.

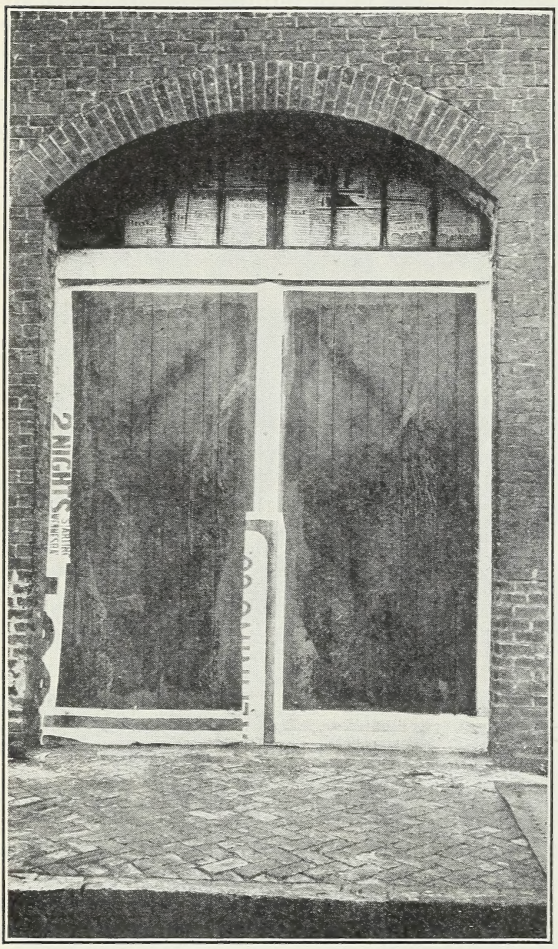

FIGURE 7.—Doors to warehouse, and transom, sealed with old bill posters cut into strips. Latticed warehouse doors in warm climates can be effectively sealed with 3 or 4 thicknesses of such material.

Old or poorly constructed buildings present a different problem. Both walls and roof must be carefully inspected for cracks or breaks. In certain types of roofs the union between the roof and the walls may be faulty and need to be tightened (figs. 8 and 9). Any loose flashing around chimneys and ventilators must be repaired, and ventilators and skylights must be sealed over (fig. 8). In some cases it is impossible to tighten a window by the ordinary method of wedging and sealing or stripping, and the entire aperture must be sealed over (fig. 9). For this purpose a fiber-reinforced waterproof building paper is excellent. It can be obtained in rolls 300 feet long and from 3 to 7 feet wide. It is a simple matter to tack it over the opening, and the edges can be sealed down with adhesive tape. If this type of paper is not available, any good tough paper can be used and can be applied by a paperhanger. Even newspapers or old bill posters will sometimes suffice if several layers are used, but the best paper for fumigation purposes is that impregnated with fiber and tar.

For stripping windows that are only slightly loose several types of materials can be used. Rolls of gummed paper, strips of newspaper smeared with grease or pasted with flour paste, and rolls of unsterilized adhesive or masking tape, known as "fumigators' tape", all have their place.

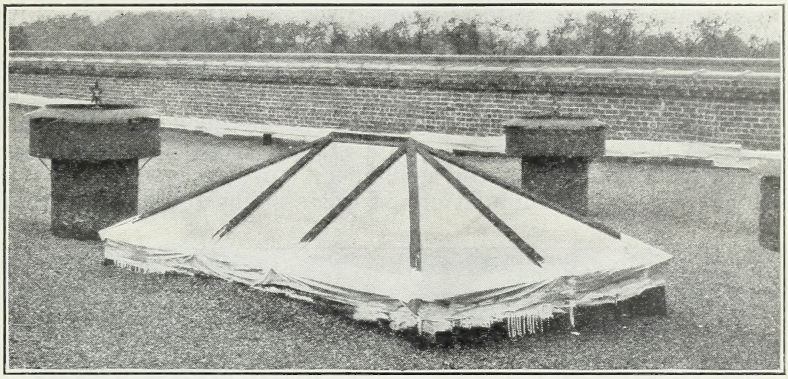

FIGURE 8.—Skylights and flashings on roof sealed in preparation for fumigation. All ventilators must also be sealed. (Photograph furnished by W. D. Reed.)

Small doors leading to the exterior of the building can be tightened by stripping around the edges with any of the materials used for the windows. Large sliding or hinged doors that fit imperfectly can be sealed most effectively by forcing a framework of 2- by 4-inch lumber covered with fiber-reinforced waterproof paper against strips of heavy felt padding (fig. 10). Such a sealing can be used many times. Another method is to caulk the doors with a paste composed

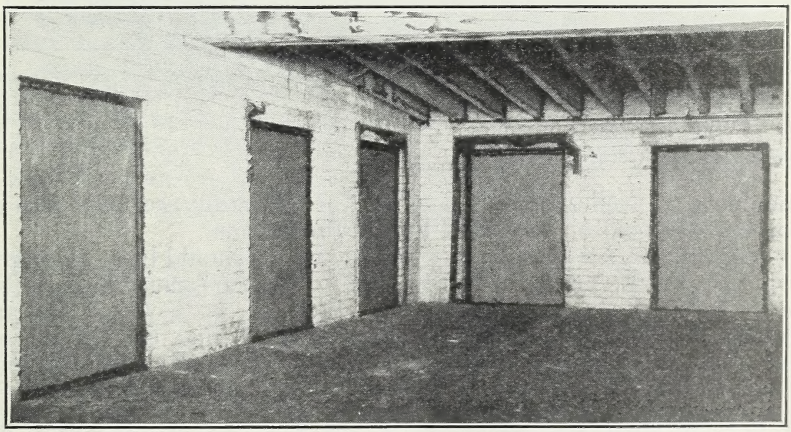

FIGURE 9.—Windows sealed on the inside with paper. Cracks about unions of rafters and walls are sealed with plastic elastic. (Photograph furnished by W. D. Reed.)

of 4 parts of asbestos to 1 part of calcium chloride mixed with a little water. The calcium chloride in the mixture will absorb enough moisture from the air to keep the paste pliable and thus insure a tight seal. It is a cheap, yet effective, sealing material and can be easily removed after the fumigation.

Buildings of more than one story are usually fumigated with each floor as a separate unit. In such cases all openings between floors must be closed, especially where pieces of machinery extend from one floor to another. Doors leading to the elevator shaft should also be carefully sealed by stripping the edges or by stuffing sacking into all cracks. If the elevator door is of the type that rolls upward, a wooden frame covered with reinforced waterproof paper, forced into place against felt gaskets, provides an excellent seal (fig. 11).

Machinery that is used to pack, mix, or handle foodstuffs in any way should be opened as completely as possible and all accumulations of materials removed. Most fumigants do not penetrate for more than a few inches into flour, meal, or similar foodstuffs; hence, such accumulations, if left in the machinery, protect insects from the effects of the gas. Accumulations of waste material under or around

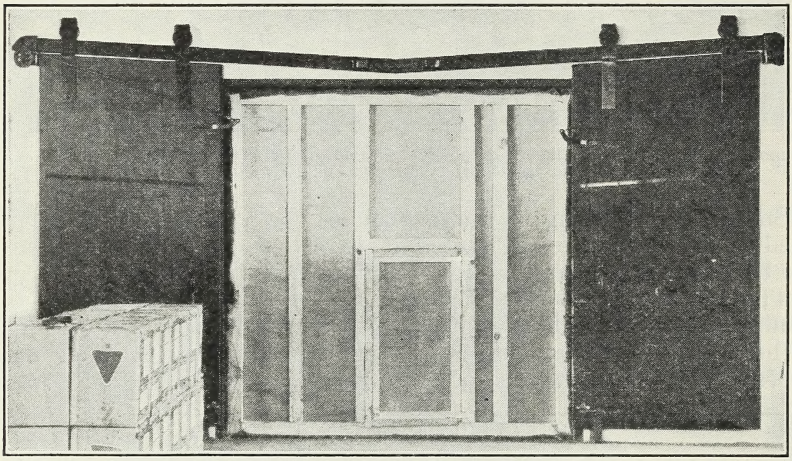

FIGURE 10.—Doorway between compartments in modern concrete storage warehouse sealed for fumigation. Framework of 2- by 4-inch lumber, covered with heavy fiber-reinforced waterproof paper, forced against strips of heavy felt padding. The fireproof doors have been rolled back. Note the small door, which also shuts against felt gaskets, for the use of fumigators. A glass window has proved useful in permitting inspection of operations.

machinery, in feed bins, or in any part of the building should also be removed and sold or destroyed before fumigation.

Commodities in warehouses or storage rooms should be so arranged as to provide the maximum circulation of the fumigant; large, solid stacks of bagged material should be avoided. In sections that are divided into small compartments or storage rooms, the connecting doors should be opened to allow a proper distribution of the gas. Where sections of a floor are large, as in many metropolitan storages, each section may be fumigated to better advantage as a single unit.

DESIRABILITY OF A HIGH TEMPERATURE DURING THE FUMIGATION

It is desirable to maintain a fairly high temperature in the building during the fumigation. Insects are not very active at temperatures below 60° F., and they become more or less dormant at 50° or below. In the dormant state they are extremely difficult to kill with fumigants. At 75° they are active and their susceptibility to the

gases increases as the temperature rises. For best results a temperature of at least 75°, and preferably somewhat higher, should be maintained throughout the fumigation.

EFFECT OF WIND VELOCITY

The velocity of the wind during the exposure influences the effectiveness of a fumigation. The fumigation should be conducted preferably when there is no wind. It is a well-established fact that the greater the velocity of the wind during a fumigation, the poorer are the results. Apparently a strong wind prevents proper distribution of the gas, and air pockets are formed which the gas does not penetrate and which, therefore, act as a protection to insects. To break up such pockets some means of circulating the air in a building during fumigation is desirable.

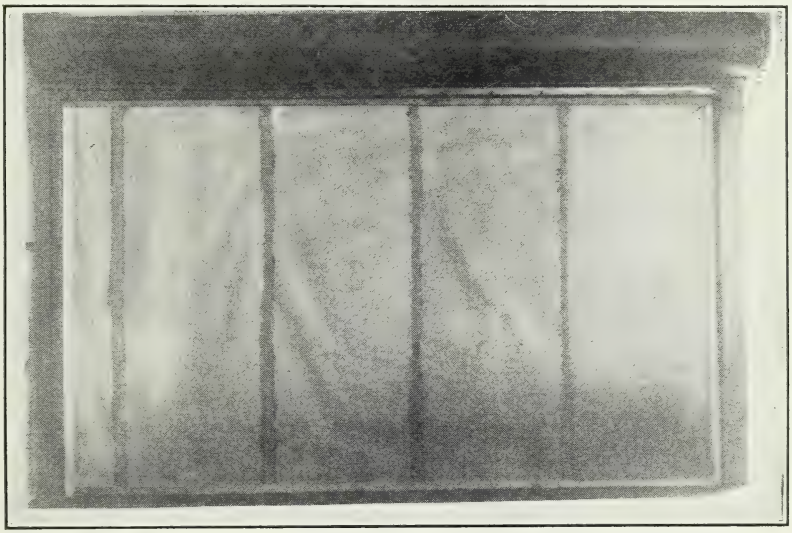

FIGURE 11.—Opening to elevator shaft sealed ready for fumigation in same manner as the doorway in figure 10. In both cases the sealing was done at the Naval Supply Depot, Naval Operating Base, Hampton Roads, Norfolk, Va.

CHOICE OF A FUMIGANT

In choosing a fumigant several factors must be taken into consideration. If the building is modern and very tight, several fumigants can be used with success, and a choice can be governed by such items as cost, efficiency, availability, safety, and effect upon the commodity to be fumigated. If the building is not particularly tight, it will be impossible to maintain a strong concentration of any gas for very long, and a quick-acting gas is the only kind that will be effective. Hydrocyanic acid is the only gas available that will kill quickly.

QUANTITY OF FUMIGANT NEEDED

The quantity of fumigant to be used will vary according to the length of exposure, the temperature, the tightness of the building,

the amount of absorption and adsorption by the commodities to be fumigated and by the walls and floors of the building itself, and the insect to be eradicated. The shorter the exposure, the lower the temperature, the looser the construction of the building, the greater the absorption and adsorption, and the more resistant the insect, the greater must be the dosage. The fumigator must exercise his own judgment in each case.

APPLYING THE FUMIGANT

The fumigant should be applied in such a way that a maximum concentration will be obtained as quickly as possible. If the concentration is slow in building up, the natural leakage from a building is often great enough to prevent a killing concentration from ever being attained.

Where it is desirable to maintain a heavy concentration over a long period, it may be necessary to use a combination of fumigants, one that will act quickly and another that will work more slowly and will serve to maintain a lethal concentration for an extended period. This is of particular importance in the fumigation of flour mills and similar structures where a deep penetration of the fumigant is essential.

The distribution of the fumigant will depend upon the structure of the building and the nature of the gas. If a lighter-than-air gas is used, the heaviest dosage must be placed on the lower floors, and if the flooring has many cracks and apertures, a much heavier dosage than usual must be placed on the lower floors. In some cases floors are so poorly constructed or so worn that the entire dosage should be applied on the first floor.

If the fumigant is not applied from the outside, the fumigating crew should be supplied with gas masks having canisters adapted for the gas that is to be used. Each operator should be familiar with the entire plan of procedure as well as with his own particular job. One man should be delegated to watch the others and to give aid in case anyone gets into trouble. Help given at the right time will prevent possibly fatal accidents.

Before the fumigation is started, the building should be thoroughly searched to make sure that no workmen or visitors are inside. During the fumigation all entrances to the building should be kept locked and usually guarded by watchmen. Placards warning people to keep out should always be tacked on all doors.

After the fumigation the building should be aired out by opening windows and doors. If possible, these should be opened from the outside. This is sometimes done by pulling open the windows on the upper floors by means of cords extending from a screw eye attached to the sash and long enough to be tied to the iron grille of the basement windows. If some such arrangement is not feasible, the windows can be opened from the inside by workmen wearing gas masks. In order to avoid accidents, two men should always work together when ventilating a building. It is important that the watchmen be instructed to prevent anyone from entering the building while it is being ventilated. A large proportion of the fatalities connected with fumigation have been due to criminal neglect on the part of watchmen.

FUMIGATION WITH HYDROCYANIC ACID GAS

For the fumigation of large buildings there is no more efficient gas than hydrocyanic acid. It is relatively inexpensive, kills with great rapidity, and, although deadly poisonous, can be handled with reasonable safety by experienced men. It can be used in nearly all types of buildings and will not injure most articles of commerce.

FIGURE 12.—Man wearing gas mask about to lower bag of sodium cyanide into a barrel containing sulphuric acid and water. If the cyanide is put in a gunny sack, there is no danger of the bottom of the bag breaking and spilling the cyanide. The cyanide should not be dropped into the acid-water mixture; it should be lowered carefully.

Hydrocyanic acid gas is commonly produced in 1 of 4 ways: (1) By generating it in a barrel, earthen ware crock, or other container from a mixture of sodium cyanide, sulphuric acid, and water—the so-called "barrel or pot" method; (2) by pumping it into the building in liquid form from cylinders—the liquid method; (3) by spreading on the floor of the building an absorbent material saturated with liquid hydrocyanic acid—the discoid method; (4) by spreading on the floor of the building a powder consisting of calcium cyanide, which combines with moisture from the air to form hydrocyanic acid gas—the powder method.

THE BARREL OR POT METHOD

The barrel or pot method of generating hydrocyanic acid gas is so called because the chemicals used are placed together in a barrel (figs. 1 and 12) or some similar container (fig. 13). This method, while more laborious than others, gives excellent results and is the safest for the use of other than professional fumigators. It can be made the cheapest method of fumigation.

Chemicals Required

Sodium cyanide (96 to 98 percent, containing 54 percent HCN), a commercial grade of sulphuric acid (66° B.), and water are the only materials required. Sodium cyanide is a white crystalline substance, which for fumigation purposes is prepared in egg-shaped lumps weighing approximately ½ to 1 ounce each. It is a violent stomach poison, and can also cause serious poisoning by being absorbed through open cuts on the hands. For this reason it is best handled with a scoop or shovel or with gloved hands (fig. 14). It can be purchased in 100-pound lots for from 16 to 22 cents per pound, and in smaller lots at a proportionally higher price.

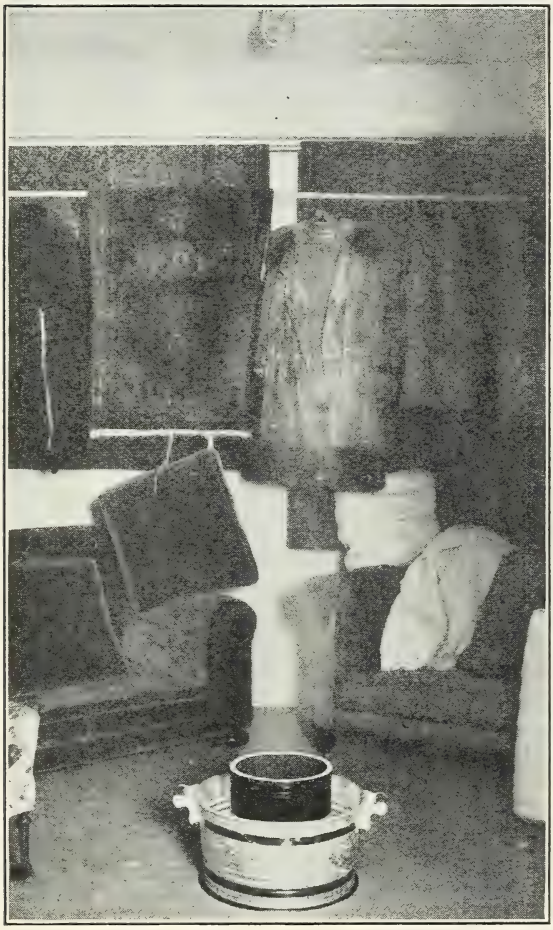

FIGURE 13.—Crock for the generation of hydrocyanic acid gas by the pot method, set in small galvanized-iron tub to prevent injury to floors in case the crock cracks.

Pure sulphuric acid is a heavy, colorless liquid, but the commercial acid used in large-scale fumigation work is slightly discolored, or murky, owing to impurities. It is highly corrosive and will cause injury if it is spattered on the clothing or body of the operator or upon the floor. It can be purchased in 11-gallon carboys for about 4 cents per pound. When large quantities of acid are required, a tilting frame will be found convenient in pouring the acid from the carboys. Workmen should learn to pour acid slowly and with caution (fig. 15), for their clothing or shoes will be damaged if a drop of acid falls on them. It is well to have easily accessible a pail of water in which some washing soda has been dissolved, for quickly washing away droplets of acid that may spatter on face, hands, or clothing.

FORMULA

For best results the chemicals should be mixed according to the following formula:

Sodium cyanide	pound	1
Sulphuric acid	pints	1½
Water[2]	do	3

PROPER ORDER OF PLACING CHEMICALS IN GENERATOR

To generate hydrocyanic acid gas by this method, the operator should first pour the water into the generator and then add the acid. If the procedure is reversed, the reaction is so violent that the operator may be dangerously burned by the spattering of the acid-water mixture. The sodium cyanide is not added to the mixture of water and acid until everything is in readiness for the fumigation, as it causes an immediate chemical reaction in which hydrocyanic acid gas is given off (fig. 16). The pure gas is colorless, but when mixed with steam produced by the chemical reaction it has the appearance of a light bluish smoke. It has an odor resembling that of peach kernels.

FIGURE 14.—Workmen weighing sodium cyanide for large warehouse fumigation. Man at right shoveling cyanide in 1-ounce lumps from 100-pound case into gunny sack held by man in center. Man at left with charge weighed about to enter warehouse and place sack beside generator.

[2] Chemical tests indicate that a 1–1½–2 formula yields more gas than the 1–1½–3 formula here recommended. The smaller quantity of water often results in a crystallization of the residue which makes the emptying of the containers after fumigation more difficult. In general large-scale work the authors have found the 1–1½–3 formula more practical and the results satisfactory.

DOSAGE

The dosage is computed on the basis of the quantity of sodium cyanide required. For general mill or factory fumigation where no large quantities of materials are stored, 1 pound of sodium cyanide will produce enough gas to fumigate 1,000 cubic feet of space, if the building is of reasonably tight construction. If the building to be fumigated is filled with merchandise, the dosage required will vary according to the nature of the merchandise. Dosages have been computed for the fumigation of the more important commodities and will be discussed in a later section of this circular.

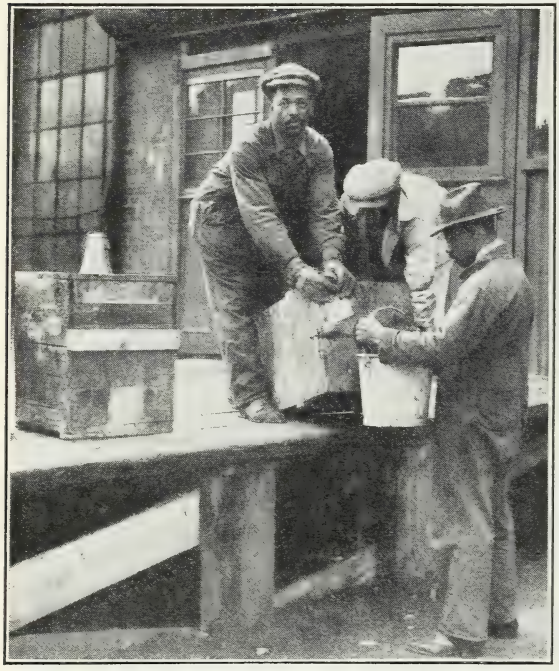

FIGURE 15.—A good illustration of workmen's indifference to spattering sulphuric acid. Most industrial plants have crews familiar with pouring acid; yet few are particular to avoid spattering and dropping acid.

THE GENERATOR

For large-scale fumigations a watertight 50-gallon wooden oil barrel (figs. 1, 12, and 16) is the most suitable generator to use. Metal barrels are not satisfactory. Barrels in which paint, glue, molasses, pitch, etc., have been stored should be avoided, for when the acid is added it may eat out these materials from between the staves, thus causing a barrel thought to be liquid-tight to leak. Barrels should be cleaned and allowed to stand full of water overnight previous to the day of fumigation. Each barrel will hold a maximum charge of 30 pounds of sodium cyanide, or enough to fumigate 30,000 cubic feet of space. When it is necessary to fumigate small rooms of a few thousand cubic feet as separate units, earthenware or stone crocks (fig. 13) of appropriate size can be used. Oil barrels sawed in half are used less often.

Each barrel generator should be set in a galvanized-iron washtub in which has been placed a pailful of water containing several handfuls of washing soda. This precaution provides for catching and neutralizing any of the acid-water mixture that may leak out of the barrel.

If 3 or 4 bricks are placed in the bottom of the washtubs for the barrels to rest on, they will not become stuck in the tubs. It is much better to have tubs large enough in diameter at the bottom so that the barrels will not come in contact with the sides.

If earthenware crocks are used, these also should be set each in a small galvanized tub. It is seldom practical to use crocks of more than 4-gallon capacity. A 3-pound charge of cyanide is the most that can be safely used in a crock of this size without danger of spattering during the evolution of the gas.

Handling Cyanide for the Generator

The weighing of cyanide should be delayed as late as possible before the fumigation is begun. The cyanide absorbs moisture, and if it remains in a paper package for a long time before fumigation, the moisture gathering on the lumps of cyanide will moisten the paper so that when the sack is picked up it may break and discharge the cyanide. Where small charges of cyanide are used, as in 4-gallon crocks, it is best to use two paper sacks, one of which

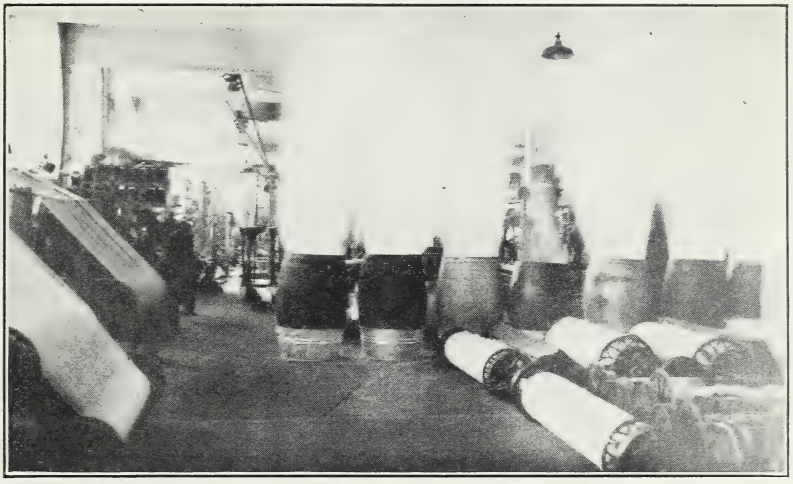

Figure 16.—Seven 50-gallon oil barrels, in tubs, arranged in line near the door of a woollen factory. The sodium cyanide has been dropped into the acid-water mixture. Note gas mixed with steam rising from the barrels. Each of these barrels had a charge of 25 pounds of sodium cyanide, the battery of 7 barrels generating enough gas for 175,000 cubic feet of mill space.

will fit easily inside the other. By wrapping the unoccupied portion of the sacks tightly about the cyanide and tying with a string, a compact package is obtained, which can easily be lowered into the acid-water mixture with one hand. If two bags are used, the operator can lower 6 or 8 charges of cyanide into the containers before the acid eats through the paper of the charge first dropped, and often he can be out of the building before any gas is evolved. If the sacks are merely tied close above the cyanide, or twisted, without wrapping, during the reaction the acid-water mixture may be forced up along the neck of the bag and over the edge of the container. If the cyanide is properly packaged, however, there will be no overflow.

When large dosages are used in barrels, sometimes as large as 30 pounds, it is safer to place the cyanide in gunny sacks. When charges in such sacks are lowered into the barrels, gas is evolved at once

and the operator must work with dispatch. The evolution of gas can be delayed by wrapping the sack in paper and tying the bundle with cord strong enough so that the bundle can be lifted and lowered into the barrel without danger of breakage. A person can then lower several charges before gas is discharged from the first.

Placing the Generators

In the fumigation of large open mills or warehouses, all the generators for one floor can be grouped in a position reasonably close to the exit. It is not necessary to distribute them throughout the room, for the gas is quickly dispersed to all parts of the enclosed space. In fact, where it is impractical to seal off the several floors of a rather small, tight building, excellent results can be obtained in calm weather by placing all the generators on the lower floor so that the gas will rise from floor to floor.

How to Generate the Gas

After the mill or warehouse has been prepared for the fumigation and the generators have been placed in their proper positions, the water and acid are measured out and distributed in the generators. The acid can be poured from the carboys into heavy galvanized-iron buckets, which will resist the action of the acid long enough for it to be distributed without accident. If crocks are used for generators, the acid must be poured into the water slowly with a rotating motion, lest the heat developed by the chemical reaction between the acid and water cause the crocks to break. If the crock should crack, the operator must empty it immediately into some handy container provided for such an eventuality.

When the water and acid have been mixed, the sodium cyanide, which has previously been weighed into the proper quantities and wrapped, should be lowered carefully into the generators. If several floors are to be fumigated separately, the cyanide should be dropped first into the generators on the top floor, and then on the next lower floor, and so on to the bottom. Starting with the one farthest from the exit (previously determined), proceed from generator to generator calmly and without delay. Do not retrace steps to a generator accidentally overlooked. If several lines of generators converge at one exit, an operator should be assigned to each line and at a predetermined signal each should start dropping the cyanide in the most distant generator in his line.

Since the gas is generated as soon as the acid-water mixture comes in contact with the sodium cyanide, the operators engaged in dropping the cyanide should wear gas masks, except for very small jobs where only 1 or 2 generators are used.

Emptying the Generators

When the fumigation is finished and the building has been thoroughly ventilated, the residue must be emptied from the generators. Sometimes the chemical reaction is incomplete because some of the sodium cyanide has not come in contact with the acid-water mixture or because the wrong proportions of the materials have been used.

Therefore, when the generator is moved, the contents are shaken up and additional small quantities of gas may be given off. For this reason the operator should breathe as little as possible or use gas masks while handling the barrels and should not hold his head over the barrel.

The residue, which is poisonous, can be disposed of by dumping it down a street drain (fig. 17) or by pouring it into a hole in the ground and covering it with soil.

THE LIQUID METHOD

Liquid hydrocyanic acid is a volatile, colorless liquid which boils at 79° F. It is marketed in cylinders containing 30 or 75 pounds. On exposure to air it gives off the same gas that is generated by mixing sodium cyanide with sulphuric acid and water. In the hands of an expert fumigator it is an almost ideal fumigant for use in large enclosures.

FIGURE 17.—Men carrying containers from a warehouse to empty into a city drain the residue from a hydrocyanic acid gas fumigation.

After a building has been prepared for fumigation, the gas is applied entirely from the outside (figs. 18 and 19). The cylinders containing the liquid hydrocyanic acid are lined up near the building, and the fumigant is forced in by compressed air. A proper distribution of the gas within the building is obtained by means of lines of pressure rubber tubing or metal piping equipped with spray nozzles. A gas mask should be worn or close at hand.

PIPING THE BUILDING

In small enclosures the gas can be distributed through rubber tubing, but in large warehouses or mills it is desirable to install a permanent system of piping. This may be constructed of iron, brass, or copper. The iron piping is the least expensive, but, owing to its tendency to rust and cause clogging of the spray nozzles, it is rarely used. Either brass or copper tubing is recommended. A flexible copper tubing three-eighths inch in diameter (fig. 20) costs about 6 cents a foot. Since it can be readily bent, elbow fittings are unneces-

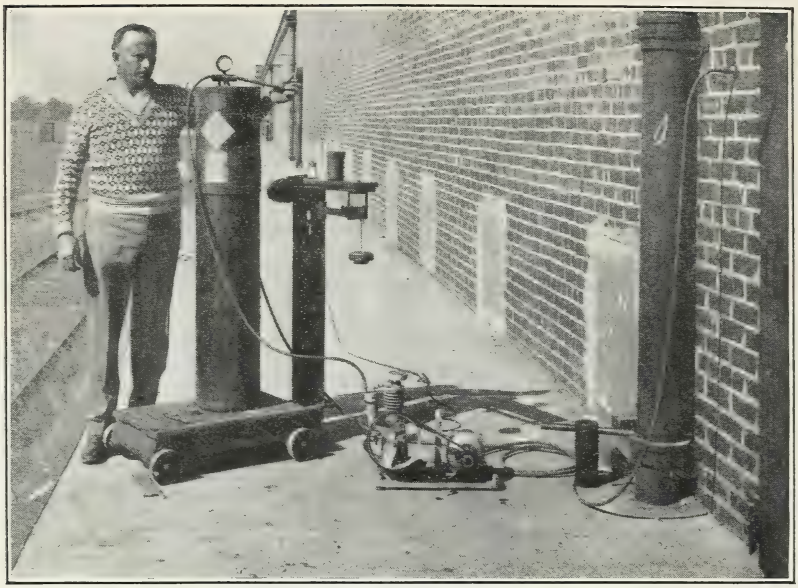

FIGURE 18.—Fumigating a tobacco warehouse with hydrocyanic acid gas, using the liquid method. The liquid hydrocyanic acid in the cylinder on the scales is being forced, by air pressure generated by a small electrically driven compressor, through the rubber tubing from the cylinder to the piping system installed inside but protruding through the walls.

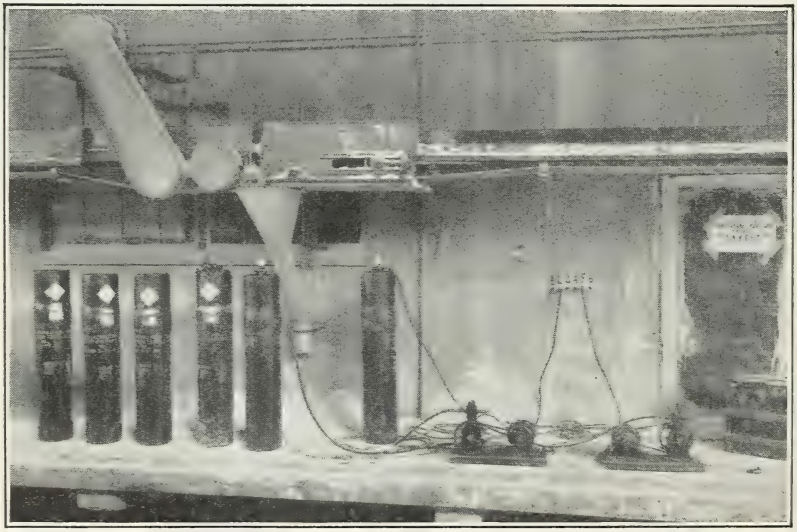

FIGURE 19.—Equipment for fumigation of flour mill from loading platform. Note 6 cylinders of liquid hydrocyanic acid, 2 electric motors, outlets in the wall leading to 6 piping systems to carry fumigant to 6 separate compartments, floors, or pipe lines within. The 2 motors are forcing, by air pressure, the liquid hydrocyanic acid in 2 of the cylinders through rubber hose into 2 of the systems of copper piping within. Note placard on door warning of danger.

sary, and compression couplings can be used, except at the main inlet, where the cylinders are connected.

In large buildings, where there are several floors and numerous branch lines must be used, each floor should be provided with a separate riser, which should be of larger tubing. A spray nozzle (fig. 21) should be provided for at least every 25,000 cubic feet of space, but there should be not more than 10 spray nozzles to a riser.

Most buildings can be piped with copper tubing at a cost of about 10 or 12 cents per 1,000 cubic feet of space. Brass tubing costs about two and one-half times as much as copper.

The piping system should be so arranged that the gas pressure will be approximately the same at all nozzles, thus insuring an even distribution. Each riser is connected to a special inlet pipe leading through the outside wall of the building to the cylinders of gas.

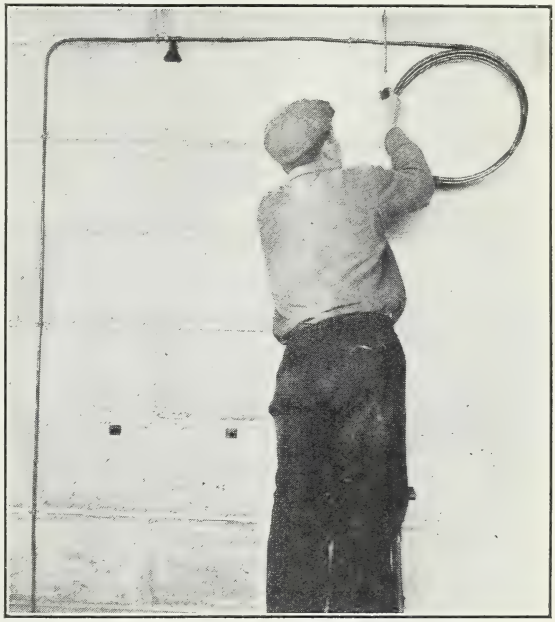

FIGURE 20.—Installation of three-eighths inch copper piping for introduction of liquid hydrocyanic acid. This piping, being flexible and easily cut with a saw, as indicated, can be run along side walls and out along rafters, or to any point where it seems best to install the spray nozzles.

APPLYING THE GAS

Each cylinder of liquid hydrocyanic acid is supplied with an inlet valve and an outlet valve. The outlet valve is attached to a steel tube connected with the bottom of the cylinder. The inlet valve leads directly into the top of the cylinder, and through it air is pumped, by means of a small compressor (figs. 18 and 19), until a pressure of about 100 pounds is obtained. The outlet valve, which has previously been connected with the inlet pipe to the building, is then opened and the gas is forced in. The pressure must be maintained until the liquid is blown through the pipes into the space to be fumigated. As soon as the required quantity of liquid hydrocyanic acid has been forced into the building, the pipe lines are blown clear and the inlet tubes capped. The time needed to pump the contents of a 75-pound cylinder into a building is approximately 7 minutes.

SAFETY PRECAUTIONS

At the conclusion of the fumigation and after the building has been well ventilated, the spray nozzles should be removed and cleaned

for storage and the pipes capped. In removing these nozzles, care must be taken to avoid accidents from the small quantities of liquid hydrocyanic acid that sometimes remain in the pipes after a fumigation. The operator should never stand directly in front of or beneath a spray nozzle that is being removed. The presence of liquid hydrocyanic acid behind a nozzle that is being unscrewed is usually revealed by a well-defined cooling sensation and sometimes by a slight odor.

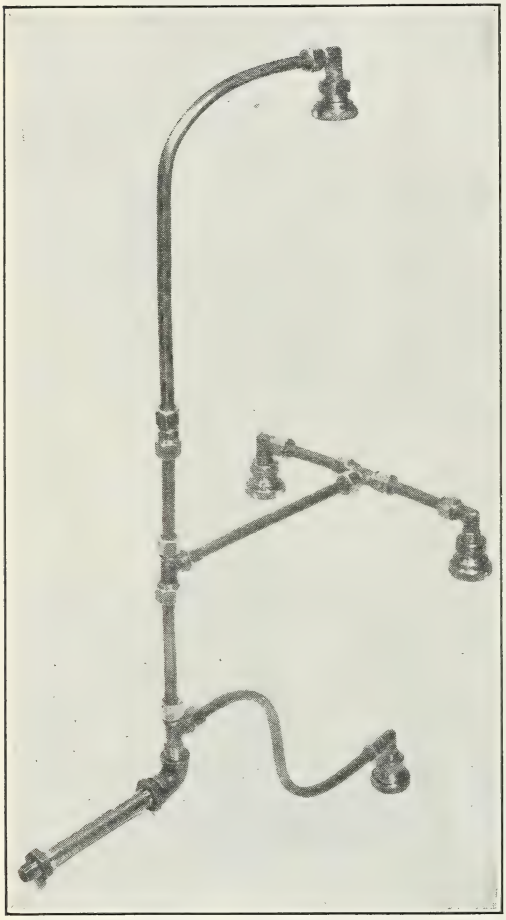

FIGURE 21.—Various attachments for spray nozzles used in fumigating a warehouse, mill, or factory with liquid hydrocyanic acid.

In fumigating with liquid hydrocyanic acid, there is always some danger that the rubber connecting hose may burst under the pressure, showering the operator with the deadly fluid. It is therefore a wise precaution to wear a gas mask while manipulating the valves of the cylinders, and also to have the clothing covered with a smock, which can be snatched off in an emergency.

THE DISCOID METHOD

For the fumigation of warehouses that are divided into sections, of mills containing machinery that cannot be easily opened up, or of apartment buildings, etc., the use of some form of solid from which hydrocyanic acid gas can be produced is often desirable, since it does away with the necessity for an elaborate piping system or for crock or barrel generators.

There are two types of such solids now on the market. One of these consists of liquid hydrocyanic acid absorbed in some inert material, from which it evaporates on exposure to air. This inert material is pressed into waferlike discoids each containing approximately one-half ounce of liquid hydrocyanic acid (fig. 22). These discoids are marketed in tightly sealed cans of various sizes and sold on the basis of the net content of hydrocyanic acid. The other type of solid is calcium cyanide, and the hydrocyanic acid is produced by chemical reaction with the moisture in the air. Its use will be discussed under the Powder Method.

Applying the Discoids

When large quantities of discoids are used, especially in hot weather, it is advisable to chill the cans before fumigating. This will greatly retard the generation of the gas and thus increase the safety of operation. If solid carbon dioxide is available, a liberal quantity thrown over the tops of the cans in each opened case a few hours before fumigating will chill the discoids. Solid carbon dioxide can usually be purchased for from 3 to 5 cents per pound. Placing cans of discoids in cold storage will have the same effect.

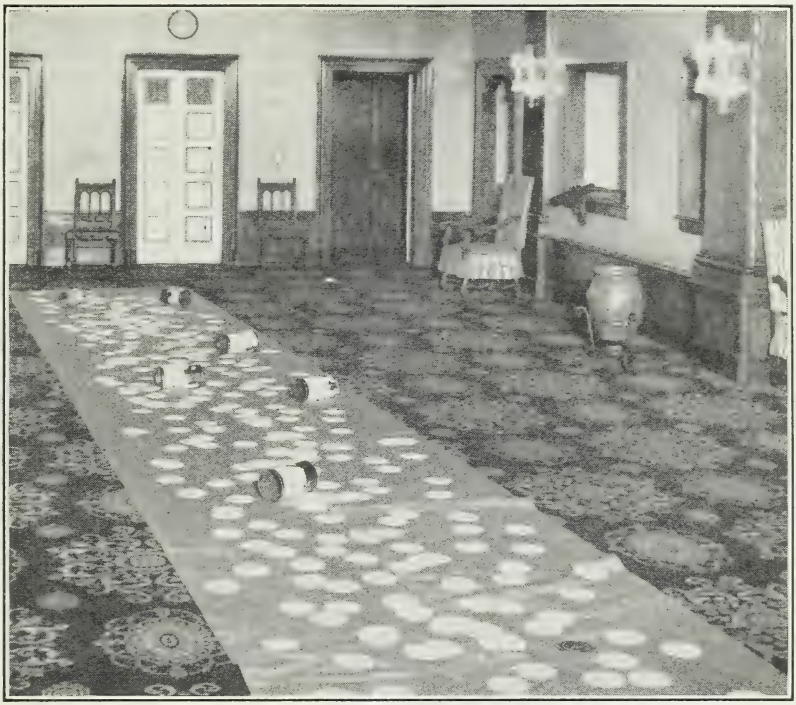

Figure 22.—Lobby of apartment house being fumigated with hydrocyanic acid gas generated by the discoid method, showing round white wafers distributed over the paper runner and the empty cans from which they have been shaken. These wafers are wet when distributed, but after the evolution of the gas they become dry and harmless.

The proper number of cans of discoids should be placed on each floor to be fumigated, and the distribution of the fumigant should be started on the top floor, always from a predetermined point and approaching the exit. One man should open the cans, using a specially devised can opener that makes a clean cut close to the rim (fig. 23), while two or more men take the opened cans and scatter the discoids over the floor or among the machinery.

Discoids should not be placed directly on painted or varnished floors or woodwork, for the liquid hydrocyanic acid is likely to injure the finish. Two or three thicknesses of newspaper or wrapping paper will provide adequate protection against any liquid that may ooze from the discoids.

When discoids are used, the fumigators are exposed to the gas while they are opening the cans and distributing the contents. Good gas masks are necessary and will prevent them from breathing poisonous fumes, but there is also some danger from the direct absorption of hydrocyanic acid gas through the skin. Williams [3] has estimated that a man protected by a good gas mask can remain in air containing 2 ounces of hydrocyanic acid gas per 1,000 cubic feet for half an hour without being affected; in a concentration of 4 ounces per 1,000 cubic feet this time should be reduced to 15 minutes, and in one of 8 ounces to 5 minutes. The same author calculates that, in distributing discoids at the rate of 8 ounces of hydrocyanic acid per 1,000 cubic feet, a fumigator will be actually exposed for the greater part of the time to from 1 to 2 ounces per 1,000 feet. Allowance is made for the fact that the fumigator is constantly moving away from the discoids and that the full quantity of the gas is not given off immediately. If the discoids are chilled before being used, the concentration to which the fumigator is exposed will be less.

FIGURE 23.—Man, protected by gas mask, removing the top from a tin can containing discoids impregnated with liquid hydrocyanic acid.

From the foregoing data it is evident that, where large quantities of discoids are used, the fumigating crew must be large enough so that the distribution of the fumigant will be speedy and no one man is exposed to the gas for a dangerously long period.

DISPOSING OF SPENT DISCOIDS

When the fumigation is finished and the building has been well ventilated, the spent discoids and the empty cans can be gathered up and thrown away. At the end of a 24-hour fumigation the discoids will retain not more than a trace of hydrocyanic acid.

[3] WILLIAMS, C. L. FUMIGANTS. Pub. Health Repts. [U. S.] 46: 1018. 1931.

THE POWDER METHOD

Calcium cyanide in dust form is used in much the same way as the discoids. On exposure to the air the powder absorbs moisture and a chemical reaction takes place by which hydrocyanic acid gas is given off.

Applying the Powder

The required number of cans of calcium cyanide are distributed throughout the building. They are then opened and the contents scattered over the floor in a layer not more than half an inch thick. To facilitate removal of the dust after the fumigation, it may be scattered on strips of paper previously laid on the floor, although it is sometimes placed directly upon the floor (fig. 24). Each can of fumigant is equipped with a special top, which the fumigator puts in place of the friction top when he is ready to use it.

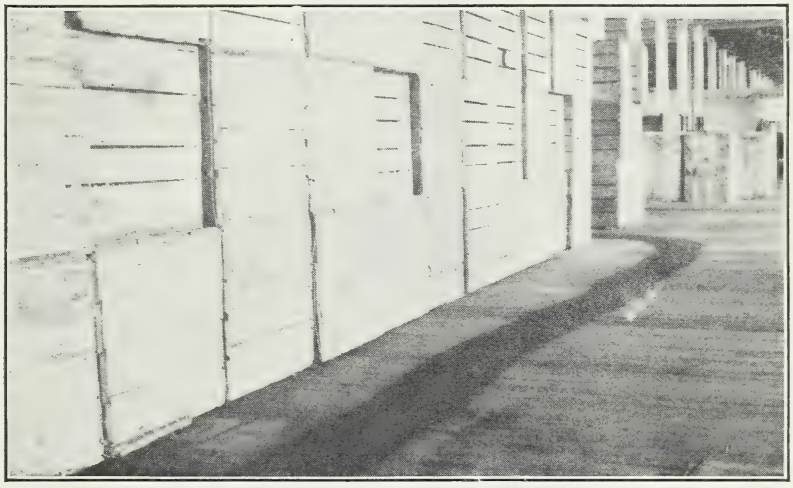

Figure 24.—Warehouse being fumigated with hydrocyanic acid gas by the powder method. Calcium cyanide in dust form is spread on the floor, usually from tin cans with perforated covers.

Inasmuch as the gas is given off very rapidly after the dust is exposed to the air, the fumigator should wear a gas mask while distributing it. As in the case of the discoids, he should begin distributing the dust at the point farthest from the exit, so that he will be working away from the gas that is being given off.

After the fumigation, the paper on which the dust is spread can be rolled up and thrown away, or the dust can be swept from the floor and placed in containers, to be disposed of immediately. The residue, which is mostly calcium hydroxide, is likely to absorb some of the hydrocyanic acid from the air; hence it is advisable to dispose of it outside the building, where small quantities of escaping hydrocyanic acid gas will harm no one. After all the hydrocyanic acid has been given off, the residue is nonpoisonous.

As the dust may be blown about while the building is being ventilated, it should be removed as soon as possible. To obviate this difficulty, as well as for other reasons, the gas is sometimes liberated

in a special apparatus (fig. 25). Air is forced by a small motor into a rubberized sack containing the calcium cyanide dust, which is kept agitated until all the hydrocyanic acid gas is liberated. The gas enters the space to be fumigated through a filtering device, which frees it of the dust.

The Dosage

To figure the quantity of calcium cyanide needed for a fumigation, it is necessary to know the percentage of available hydrocyanic acid it contains. This percentage will be found on the label of the can. If, for example, the dust contains 50 percent available hydrocyanic acid, 1 pound will give off as much gas as 8 ounces of liquid hydrocyanic acid or 1 pound of sodium cyanide. Calcium cyanide sells for about $1.35 per pound.

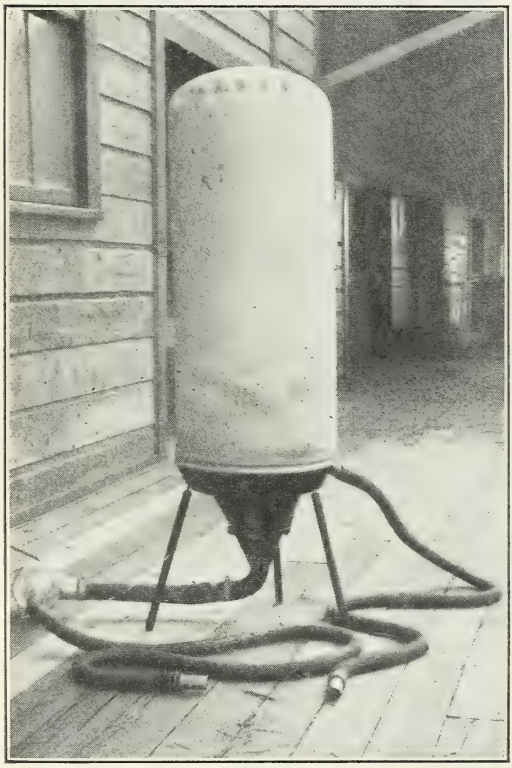

Figure 25.—Apparatus for passing air through calcium cyanide dust in such a way that the hydrocyanic acid gas evolved will be free from the dust.

FUMIGATION WITH CHLOROPICRIN

Chloropicrin, although not so popular as hydrocyanic acid, is sometimes used as a general fumigant for mills and warehouses. Chloropicrin is a colorless or slightly yellowish liquid a little more than one and a half times as heavy as water. It has a boiling point of 233.6° F. and on exposure to air evaporates slowly, forming a vapor that is about five times as heavy as air. It can be purchased in cylinders of from 1 to 100 pounds' capacity at a cost of about $1.35 per pound. The gas is nonexplosive and noninflammable as ordinarily used, is extremely toxic to insects and also to man, and has an extremely irritating effect upon the eyes and respiratory passages of man. This last characteristic insures against the probability of anyone accidentally entering a building filled with the gas. A gas mask equipped with a canister especially designed for the purpose must be worn when fumigating with chloropicrin.

There are several methods of applying chloropicrin as a general mill or warehouse fumigant. The simplest of them is to draw the required quantity of liquid from the cylinder in which it is mar-

keted into a sprinkling can and sprinkle it over the floor or commodity or into the machinery. It should not be applied directly on painted or varnished surfaces. Where there are several stories to a building, each floor should be sealed off from the others, since the fumes are so heavy that they tend to concentrate on the lower floor. If the floors cannot be made gastight, a greater concentration should be applied on the upper floors.

Owing to the rather high boiling point of chloropicrin and consequent slow rate of evaporation, it is sometimes desirable to hasten the process of vaporization by applying the liquid in the form of a spray or fine mist, or by using a mixture of equal parts of chloropicrin and carbon tetrachloride or trichloroethylene. At temperatures above 70° F., however, satisfactory results can be obtained by merely applying the straight chloropicrin with a sprinkling can.

In mills that are equipped with machinery for handling foodstuffs, it may be desirable to apply the chloropicrin directly into the machinery where the heaviest infestation is likely to be found. In such cases the fumigant can be applied with either a sprinkling can or an atomizer. One-pound cylinders of chloropicrin charged with carbon dioxide, to which a short length of hose and a spray nozzle are connected, can also be obtained for treating machinery. The nozzles are inserted into holes bored into elevator legs or other parts of the equipment, and the gas is released by opening a valve on the cylinder.

An objectionable feature of chloropicrin is that considerable time is required to ventilate a building after a fumigation. Because it does not evaporate rapidly, it clings to fumigated commodities with great tenacity.

FUMIGATION WITH ETHYLENE OXIDE-CARBON DIOXIDE MIXTURE

Warehouses and storage rooms that are of modern tight construction can be successfully fumigated with a mixture of ethylene oxide and carbon dioxide. This mixture is put up in cylinders in the proportion of 1 part by weight of ethylene oxide to 9 parts of carbon dioxide. It is noninflammable, and is not sufficiently toxic to human beings to make its application unpleasant or dangerous. It leaves no obnoxious odor or poisonous residue on the commodity fumigated. The mixture is sold in 30- and 60-pound cylinders at prices ranging from 14.5 to 16 cents per pound, f. o. b. the factory.

The application of the ethylene oxide-carbon dioxide mixture is exceedingly simple. The requisite number of cylinders are placed in the room to be fumigated and the valves opened. The pressure of the carbon dioxide automatically discharges the contents of the cylinders in the form of a very fine mist, which vaporizes at once (fig. 26). A cylinder of the mixture will empty itself in about 5 minutes after the valve has been opened wide.

When the valves are opened wide, the force of the escaping gas often causes the cylinders to topple over. To avoid this, the cylinders can be lashed to the walls of any stationary object, or several cylinders can be lashed together with the discharge vents pointing in opposite directions.

Unless a large number of cylinders are used in a fumigation, the valves can be opened without the use of a gas mask, although it is not advisable to stay in a strong concentration of the gas for any appreciable length of time. Before starting the fumigation it is well to see if the valves on all the cylinders can be opened easily by hand; any that are stuck should be loosened with a wrench.

If desirable, a storage room can be piped in the same manner as for liquid hydrocyanic acid, and the ethylene oxide-carbon dioxide released into the room from the outside. The cylinders are all equipped with fittings that can be connected with the piping system (fig. 27).

Where the floors are painted or varnished, the cylinders should be placed in shallow pans or on several thicknesses of newspaper, to prevent damage in case the liquid should run down the sides of the cylinder.

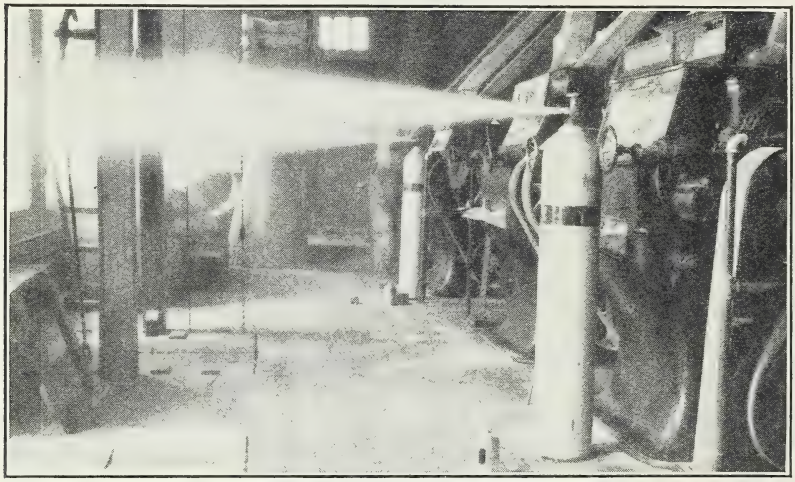

FIGURE 26.—Cylinders of ethylene oxide-carbon dioxide mixture being emptied automatically by the pressure of carbon dioxide within.

This mixture is very effective in rooms that are nearly airtight, but it should not be used in rooms that are loosely constructed.

After the fumigation and ventilation all that is necessary is to roll the empty cylinders out of the room and return them to the owner.

FUMIGATION WITH METHYL FORMATE-CARBON DIOXIDE MIXTURES

Warehouses and storage rooms that are thoroughly modern in construction can be fumigated with mixtures of methyl formate and carbon dioxide. Ordinarily these mixtures are used only in special fumigation vaults. The value of methyl formate as a fumigant was first established by the experimental work of this Department. Alone, its vapors are explosive and inflammable in the presence of fire in any form; hence, mixtures with carbon dioxide have been developed, the vapors of which are entirely free from the fire and explosion hazard.

The methyl formate-carbon dioxide mixtures are sold at 10 cents per pound, f. o. b., in steel pressure cylinders containing 50 pounds. The liquid is discharged under its own pressure. When used in connection with vault fumigation, the cylinder is set on platform scales close to the vault wall, through which the desired dosage is discharged into the vault by means of easily made metal connections. When the scales indicate that the required poundage has been discharged, the cylinder valves are closed.

The mixture is discharged as a fine mist, which immediately vaporizes. The vapors seem to be harmless to food and other commodities thus far treated, and they are only slightly toxic to man as he ordinarily comes in contact with them in fumigation work. The

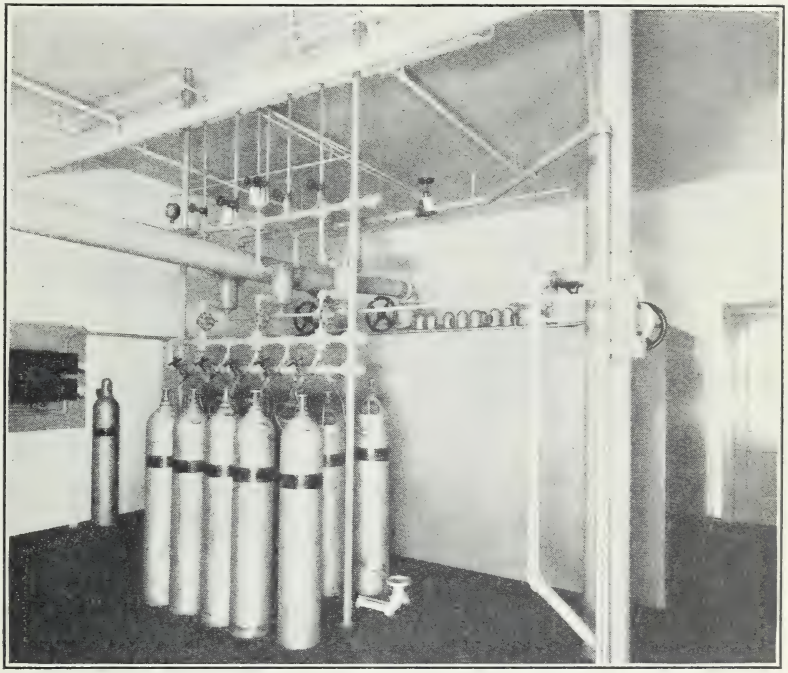

FIGURE 27.—Battery of 10 cylinders of ethylene oxide-carbon dioxide mixture attached to manifold, heaters, and distributing pipes connecting with storage vaults (not shown) in room. In lower background is a 6- by 8- by 10-foot metal fumigation vault, which opens into the room beyond.

recommended dosage, per 1,000 cubic feet of empty space, is 28 pounds, with an exposure of from 12 to 24 hours. Several mixtures have been offered to the public, but one containing about 15 percent of the methyl formate seems to be the most effective and safe. This fumigating mixture is similar to the ethylene oxide-carbon dioxide mixture in the manner in which it is marketed and used.

VAULT FUMIGATION

Many establishments have use for a small fumigation vault for the treatment of incoming raw materials, returned goods, outgoing products, etc. Such a vault may be constructed of any material that can be made gastight or reasonably so.

Several types of metal vaults (fig. 28) can be purchased knocked down ready for assembling. These are excellent in every way. Highly satisfactory vaults can be constructed of concrete, brick, or hollow tile. The brick (fig. 29) and hollow-tile (fig. 30) vaults should be finished inside with a layer of Keen's cement and 1 or 2 coats of paint. Wooden vaults with a metal lining are also popular. It is possible to purchase 14-gage sheet metal cut up into sections for constructing a vault 8 by 10 by 12 feet. When welded together, the sections form an excellent gastight lining.

The cheapest type of vault is made of wood. An efficient vault can be constructed of two layers of 2-inch standard flooring separated by a layer of heavy roofing paper. If the edges of each board are painted with heavy white-lead paint just before the tongue and groove are forced tightly together, the walls are even tighter. The floor, walls, and roof should be of the same tight construction. The

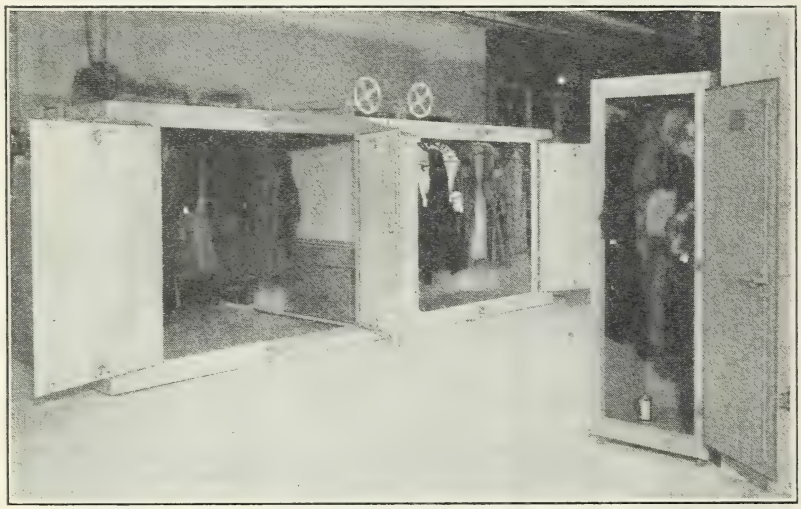

FIGURE 28.—Two types of metal vaults such as can be purchased or built according to space and commodity need. These vaults are used for treating the day's arrival of fur coats offered for summer storage. After an overnight fumigation in these vaults the furs are removed to large permanent storage vaults.

interior should be given 2 or 3 coats of any good paint. An aluminum paint is sometimes used to advantage.

All types of vaults should be equipped with a refrigerator or safe type of door, well gasketed to make it gastight.

A ventilating system capable of quickly removing the fumigant from the vault after the fumigation is essential. If the vault is set up inside a building, the ventilating stack must extend outside the building and preferably above the roof.

It is sometimes desirable to install an electrical heating unit, controlled by a thermostat, so that a constant high temperature can be maintained throughout the fumigation.

For applying the fumigant several different methods can be used. For heavier-than-air gases a shallow evaporating pan or trough should be installed near the ceiling of the vault, with a feed pipe extending outside (fig. 30). The fumigant can then be run into the

FIGURE 29.—Two outdoor fumigation vaults under one roof, built of brick, finished on the inside with Keen's cement, and equipped with doors shutting against rubber gaskets to prevent gas leakage. Note ventilators in roof to aid in ventilation when lighter-than-air gas is used. (Photograph by Perez Simmons.)

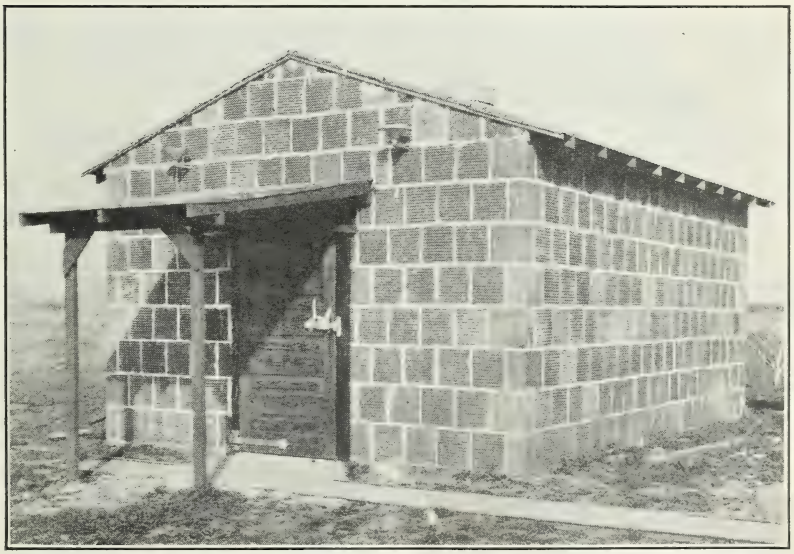

FIGURE 30.—Outdoor structure built for fumigation of dried fruits. It is made of hollow tile, plastered on the inside with Keen's cement, and equipped with a refrigerator-type door. Note funnel-shaped openings above the door, through which a liquid fumigant can be poured into evaporating trays suspended from the ceiling of the vault. (Photograph by Perez Simmons.)

evaporating pan by gravity or compressed air. If liquid hydrocyanic acid or the ethylene oxide-carbon dioxide mixture is to be used, a short piping system with one or more spray nozzles can be installed (figs. 20, 21, and 27).

USE OF FUMIGANTS SUITABLE ALSO FOR LARGE SPACES

Hydrocyanic acid, chloropicrin, ethylene oxide-carbon dioxide mixture, and the methyl formate-carbon dioxide mixtures are all suitable for vault fumigation, and they can be used in the manner described for the fumigation of large spaces. If hydrocyanic acid is used, the pot or the discoid method is best adapted for vault fumigation, since only small quantities of the chemical are used at one time. Chloropicrin can be applied by pouring the dosage into the evaporating pan or by forcing it in through a piping system with compressed air. The ethylene oxide-carbon dioxide mixture and the methyl formate-carbon dioxide mixtures are applied through a piping system and can be administered by connecting the cylinder to the system (fig. 27) and opening the valve. If the cylinder is placed on a platform scale, it is an easy matter to let in the quantity desired.

USE OF OTHER FUMIGANTS

Various other fumigants, not suitable for warehouse fumigation, can also be used successfully for vault fumigation. These are carbon disulphide, ethylene oxide, ethylene dichloride-carbon tetrachloride, and carbon tetrachloride.

CARBON DISULPHIDE

Carbon disulphide is a colorless, volatile liquid, which boils at 114.8° F. On exposure to air it evaporates, forming a heavy vapor that is very toxic to insects.

It is applied by pouring the liquid into the evaporating pan of a vault at the rate of about 5 pounds per 1,000 cubic feet of space. If the vault is not tight, more fumigant should be used. It should not be used at temperatures below 70° F., and the exposure should be at least 12, and preferably 24 hours.

The vapors of carbon disulphide, when mixed with air in certain proportions, are highly inflammable and explosive; hence this fumigant should be used only where the fumigation vault is isolated from other buildings, and where the fire hazard can be controlled.

Mixtures of carbon disulphide with other chemicals, such as carbon tetrachloride and sulphur dioxide, for the purpose of reducing the fire hazard are now on the market. Although not absolutely noninflammable, they can be used with comparative safety. Their efficacy is directly proportional to the carbon disulphide content, and they should be used accordingly.

The vapors of carbon disulphide are poisonous to human beings if breathed for an extended period. Exposure to light concentrations may induce a feeling of giddiness, which, however, will quickly pass off on coming out into the fresh air. Small quantities of carbon disulphide can be handled without danger by the ordinary person, although persons having any heart trouble should take little part in its application.

Carbon disulphide ranges in cost from about 6 cents a pound in 500-pound lots to 30 cents a pound in 1-pound lots.

CARBON TETRACHLORIDE

Carbon tetrachloride is a colorless, volatile liquid having a boiling point of 170° F. Its vapors are noninflammable, and therefore it is sometimes recommended as a fumigant in place of carbon disulphide.

It is not very effective when used alone against insects that infest stored products and should be chosen only when no other fumigant will do. Its chief use is for mixing with more toxic fumigants to reduce the fire hazard.

To be at all effective, it must be used at a temperature of 75° F. or higher, and at the rate of at least 30 pounds per 1,000 cubic feet of space. It is applied by pouring it into the evaporating pan of the vault. The vapors of carbon tetrachloride have an anesthetic effect when breathed by man. Although they are not quickly toxic, it is not safe to remain for any length of time in a strong concentration of the gas.

The cost of carbon tetrachloride ranges from about 5.8 cents per pound in large quantities to 10 cents per pound in small lots.

ETHYLENE DICHLORIDE

Ethylene dichloride is a colorless liquid with an odor similar to that of chloroform. It has a boiling point of 183.2° F., and on exposure to air it evaporates, forming a gas that is more than three times as heavy as air. It is an effective fumigant in gastight vaults, but owing to its high boiling point it should be used at a temperature of at least 70° F. and preferably somewhat higher.

The vapors of ethylene dichloride are slightly inflammable. It is therefore customary to use this fumigant in combination with some noninflammable chemical, such as carbon tetrachloride or trichloroethylene. A mixture of 3 volumes of ethylene dichloride with 1 volume of carbon tetrachloride or trichloroethylene is free from fire hazard under ordinary conditions, and is an effective fumigant when used at the rate of 14 pounds per 1,000 cubic feet of space.

This fumigant is applied by pouring it or forcing it under pressure into the evaporating pan of the vault. A small fan blowing on the surface of the liquid insures a more rapid vaporization of the fumigant and hastens its killing action.

The vapors of ethylene dichloride have an anesthetic effect upon man, and although it is safe to use in small quantities, one should not be exposed to a heavy concentration of the gas for more than a very brief period without a gas mask.

The mixture of ethylene dichloride and carbon tetrachloride or trichloroethylene has no corrosive action on metals or any bleaching or staining action on textiles of any sort. It is suitable for treating grains and seed, but should not be used for foodstuffs with a high fat content, for they are likely to retain a disagreeable odor and taste after fumigation.

Ethylene dichloride can be purchased separately or already mixed with carbon tetrachloride or trichloroethylene. Alone or mixed

with carbon tetrachloride it sells for from 6.4 to 9.9 cents per pound, f. o. b. the factory, plus certain freight allowances. There are approximately 10 pounds to the gallon.

ETHYLENE OXIDE

Ethylene oxide is a colorless gas at ordinary temperatures, but below 50° F. it is a colorless liquid. It has a boiling point of about 57.2°, and therefore it can be used with success at temperatures considerably below 70°.

The concentrated vapor of ethylene oxide is inflammable, but concentrations up to 3½ pounds per 1,000 cubic feet of space are nonexplosive and noninflammable.

A dosage of 2 pounds per 1,000 cubic feet will give satisfactory results in a tight vault, with an exposure of from 10 to 20 hours. The liquid, which is sold in cylinders, can be drawn off into a measuring container and poured into the evaporating pan of the vault. Owing to its extreme volatility, it should not be drawn from the cylinder until the fumigation chamber is ready for the charge.

Ethylene oxide gas is not injurious to fumigated commodities, and no obnoxious odor or poisonous residue is left upon them. The gas is not highly toxic to man and can be handled in small quantities without danger or discomfort. Nevertheless, the operator should avoid breathing the fumes for any length of time and should not enter a heavy concentration without wearing a gas mask.

If ethylene oxide is used alone, it is advisable not to operate an electric fan inside the vault, lest an inflammable concentration of the gas has been accidentally obtained.

Ethylene oxide can be purchased in cylinders containing 3½, 18½, 75, or 195 pounds, at prices ranging from 50 cents to $2 per pound, according to the quantity purchased and size of cylinders, f. o. b. factory, east of the Rocky Mountains; for deliveries from the Los Angeles and San Francisco warehouses prices are 5 cents per pound higher.

BIN FUMIGATION

Bins used for the storage of foodstuffs. yarn, hosiery, etc., frequently need to be fumigated. For this purpose any of the heavier-than-air gases, such as carbon disulphide, chloropicrin, ethylene oxide, or ethylene dichloride-carbon tetrachloride mixture, can be used, provided it is suitable for treating the commodity stored in the bin.

The fumigant should be sprinkled evenly over the surface of the contents of the bin, and the bin should then be covered as tightly as possible. As the fumigant evaporates, the vapor, being heavier than air, gradually penetrates the material from the top to the bottom.

The quantity of fumigant needed will depend upon the tightness of construction of the bin, the type of material to be fumigated, and the fumigant being used. Bins are seldom so tight as fumigation vaults; hence larger dosages are necessary.

VACUUM FUMIGATION

Fumigation by vacuum (figs. 31, 32, and 33) consists in placing the commodities to be fumigated in a gastight steel chamber, removing the air, and replacing it with a gas lethal to insects. By this method there is immediate penetration of commodities by the gas, and insects are killed with a rapidity that is not obtainable in an atmospheric vault. The length of exposure required in vacuum fumigation ranges from 1 to 3 hours, as compared with from 10 to 24 hours under atmospheric conditions. This process, therefore, has a considerable appeal in industries where speed is essential, as in the handling of foodstuffs and other commodities.

In addition to reducing the time of exposure, vacuum fumigation has several other advantages. At the end of a fumigation the gas can be speedily removed from the treated commodities by a process known as "air washing", which consists in drawing a vacuum of 27 inches and breaking it with air. Furthermore, by this method workmen are not exposed to the fumes of the gas. The disadvantages are the original cost and upkeep of the equipment and the larger quantity of fumigant needed.

EQUIPMENT

Vacuum chambers are usually cylindrical, although rectangular tanks are increasing in popularity. They are made in all sizes, from laboratory outfits with a capacity of about 1 cubic foot up to those capable of holding one or more carload lots. The size of the chamber will depend on the type and quantity of material to be fumigated and the space available for it in the factory. Some firms prefer to have two tanks that can be operated with one set of equipment. While one tank is under fumigation, the other can be loaded or unloaded and the fumigation crew kept continuously busy.

The tanks are usually installed so that small trucks or factory skids on narrow-gage tracks can be run into them. If the vacuum chamber is equipped with a door at each end, the trucks can be run in at one end and out the other, so that the fumigated products will not interfere with the next load. In some factories one end of the vacuum chamber opens into the receiving room and the other end into the general storage room. Raw materials likely to be infested are then fumigated before they are placed in the general storage rooms.

The doors of the vacuum tank should be so balanced and hung that they can be quickly opened and closed by one man. The gaskets should be durable and at the same time provide a gastight seal. The efficiency of a tank depends largely on the tightness with which the doors fit. A well-built tank should hold a vacuum without perceptible loss throughout the average fumigation period.

Many tanks are equipped with steam coils or electric heating units to maintain a favorable temperature during fumigation. A thermostat should be used to maintain a constant temperature and to prevent overheating.

Each installation requires a vacuum pump capable of drawing a 28-inch vacuum in 10 minutes or less.

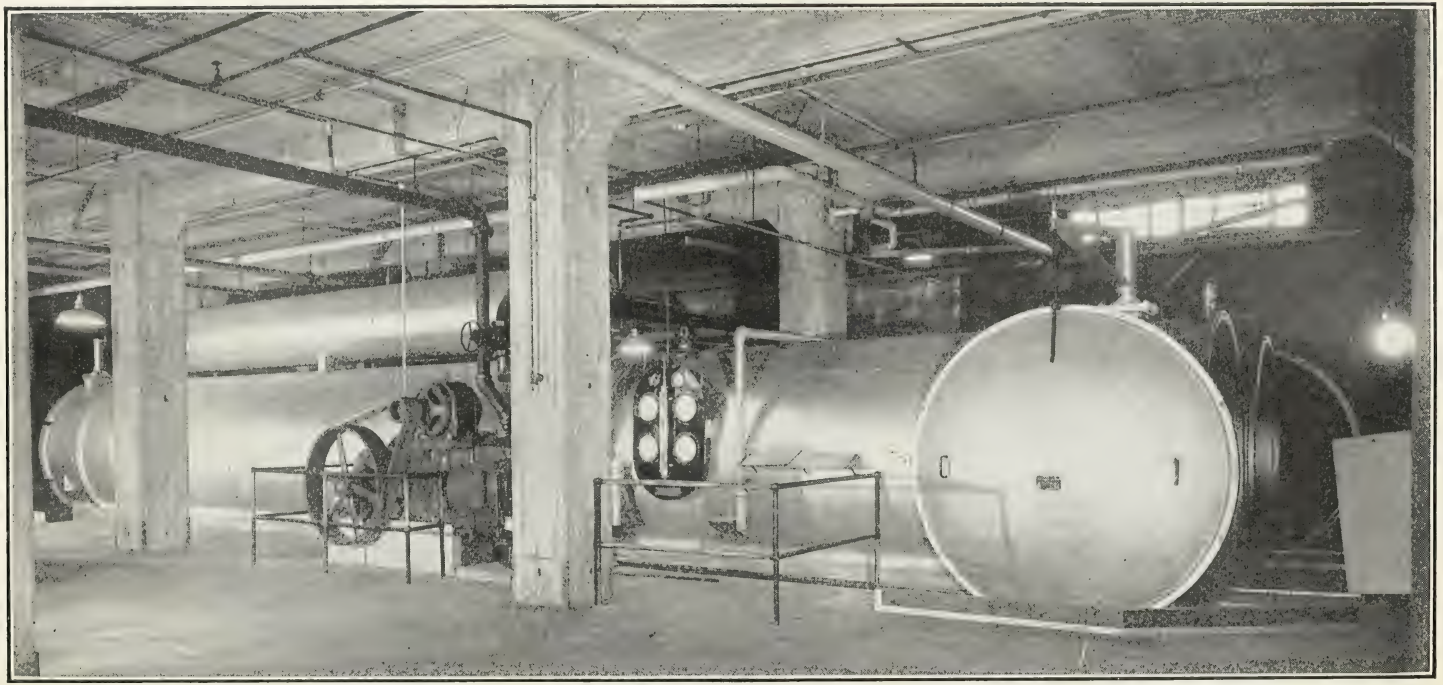

FIGURE 31.—A two-tank vacuum fumigation plant, installed in a large tobacco establishment in North Carolina. Each tank is 63 feet long by 8 feet in diameter and takes a load of 43,000 pounds of Turkish tobacco per fumigation. Note doors at right swinging away from ends of tubes, the powerful vacuum pump, the automatic devices for recording vacuum and temperature, and the cylindrical accumulator on top of tank. Attachments for introducing the fumigant are on the opposite side.

The use of a vaporizer in connection with a vacuum chamber increases its efficiency by insuring the entrance of the fumigant in a gaseous state. The most common type of vaporizer consists of a steel tank in which steam is generated by means of electric heating elements. A copper coil, through which the fumigant is conducted, runs through this steam-heated tank and is so designed that the fumigant is in gaseous form by the time it reaches the vacuum chamber. If carbon disulphide is used, a specially designed vaporizer is required, since it must be mixed with carbon dioxide before it is admitted to the fumigating chamber.

In some modern vacuum outfits an accumulator tank is utilized to vaporize and heat the fumigant before drawing it into the vacuum

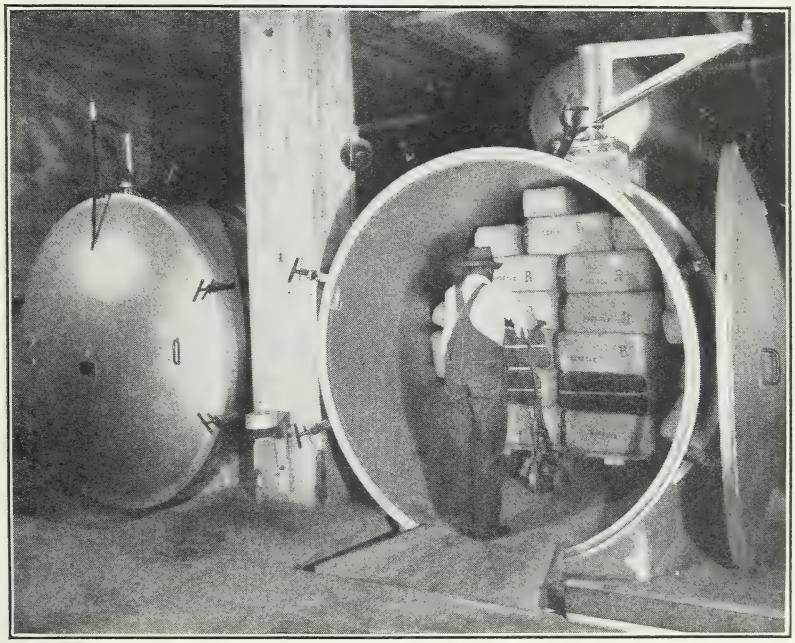

FIGURE 32.—End view of vacuum equipment shown in figure 31. Tank at left closed and under fumigation. Tank at right nearly loaded with 43,000 pounds of Turkish tobacco. These tanks will treat all incoming tobacco placed in this storage establishment. Note end of cylindrical accumulator on top of tank at right.

chamber. It consists of a tank with a heating coil into which the dosage is drawn, and in which it can be held until ready for use.

Hydrocyanic acid, chloropicrin, ethylene oxide-carbon dioxide mixture, methyl formate-carbon dioxide mixture, and carbon disulphide-carbon dioxide mixture are used in vacuum fumigation. The dosage required depends on the commodity to be fumigated and the length of exposure.

PROCEDURE

The commodity to be fumigated is first loaded into the vacuum chamber, the doors are tightly closed, and a vacuum of about 28 or

29 inches is drawn. The proper dosage of fumigant is then admitted through the vaporizer or accumulator. The remaining vacuum should be held without change for the duration of the fumigation, since it has been found that better results are obtained if the vacuum is held instead of being broken with air. A chart record (fig. 34) should be made of each fumigation in case it is needed for future reference.

At the end of the fumigation the gas is pumped out of the chamber and the vacuum is broken with air. If desired, the fumigated

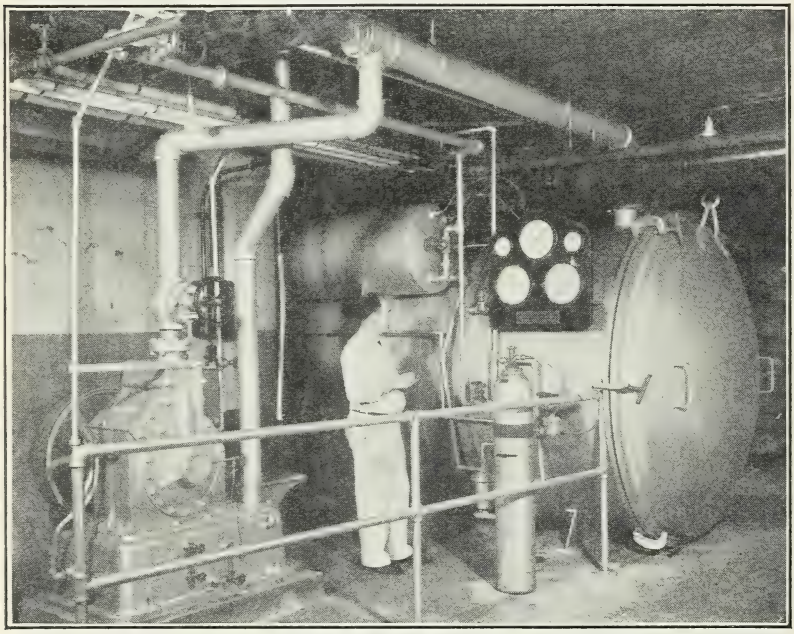

FIGURE 33.—Portion of vacuum fumigator installed in a large candy establishment. Note vacuum pump in left foreground; cylindrical accumulator on tank; gages for automatically recording pressure, vacuum, and temperature; and cylinder of the ethylene oxide-carbon dioxide mixture in front of operator. Cylinders of methyl formate-carbon dioxide mixture are attached in the same manner.

products can be "air-washed" several times by alternately drawing and breaking a vacuum of about 27 inches.

Commodities taken from cold storage should be allowed to come up to room temperature before they are loaded into the vacuum tank. Insects that have been chilled are in a dormant state, and their resistance to fumigants is increased. This resistance is retained for several hours after they are brought into a heated atmosphere, and is therefore not overcome during the time they are in the heated vacuum chamber. If the infested commodities are allowed to warm up to room temperature before fumigation, the insects will regain their normal activity and lose their resistance to fumigants.

FUMIGATION OF VARIOUS COMMODITIES

Since it is impossible to discuss here in detail the fumigation of all the many types of commodities that become infested with insects, only those commodities most often fumigated in commercial establishments are included in this circular. The fumigation of grain in bulk on the farm and in the terminal elevator is discussed in other publications of the Department.[4] No attempt is made to

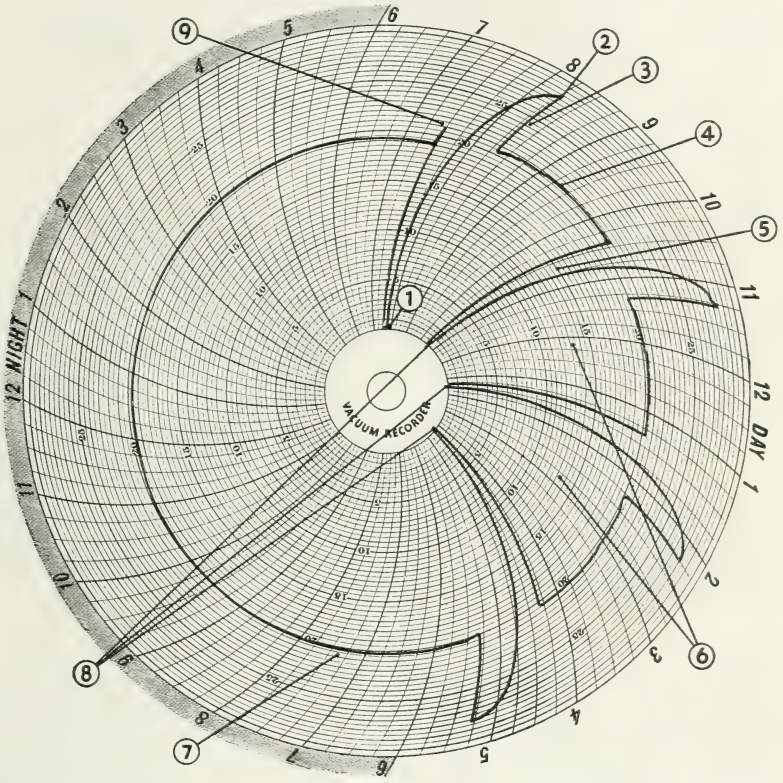

FIGURE 34.—Automatic record of four vacuum fumigations conducted during a period of 24 hours. Hours of day and night are indicated on the circumference of the chart. Figures in circles indicate: (1) vacuum pump started; (2) chamber exhausted to 28.5 inches of mercury; (3) fumigant (ethylene oxide-carbon dioxide mixture) introduced; (4) treatment period of 2 hours; (5) vacuum pump operating and breaker valve opened simultaneously, providing an air wash of product fumigated; (6) treatment cycles similar to (4); (7) last fumigation of day allowed to continue overnight; (8) doors opened, commodity removed, and a new lot placed in chamber; (9) vacuum pump started before breaker valves were opened, accounting for the rise in vacuum at this point.

discuss the fumigation of any commodity from a quarantine standpoint. For more detailed information regarding the treatment of any commodity discussed in the following pages, or regarding commodities not mentioned, the reader should direct inquiries to the Bureau of Entomology and Plant Quarantine, United States Department of Agriculture, Washington, D. C.

[4] Farmers' Bulletin 1260, Stored-Grain Pests, and Farmers' Bulletin 1483, Control of Insect Pests in Stored Grain.

CONFECTIONERY

Since the insect problems of the candy and nut-meat industries are rather closely associated, it seems logical to discuss them under one heading. Nut meats are highly susceptible to insect attack, and because they are used in large quantities in the manufacture of candy, they constitute an important source of insect infestation in the candy factory.

Most firms handling nut meats attempt to ship only insect-free nuts. To do this they keep their factories and storage warehouses as free from infestation as possible, in addition to fumigating all outgoing merchandise. A yearly fumigation of the factory with hydrocyanic acid gas, supplemented by constant attention to cleanliness, will reduce insect infestation to a minimum. A dosage of 8 ounces of liquid hydrocyanic acid or its equivalent per 1,000 cubic feet is sufficient for this purpose. An exposure of 24 hours is desirable.

Where nut meats in the shell are stored without cold storage, it sometimes becomes necessary to fumigate the warehouses also. Hydrocyanic acid is the best fumigant for this purpose and should be applied at the rate of 16 ounces of liquid hydrocyanic acid or its equivalent per 1,000 cubic feet. Excellent results can be obtained in tightly constructed warehouses, even though the bagged nuts are piled in large stacks. If possible, a 48-hour exposure should be given.

Nuts absorb considerable hydrocyanic acid gas, and therefore a warehouse that has been fumigated cannot be aired out very quickly. Large stacks of bagged nuts hold the gas and give it off slowly over a period of several days. In one fumigation conducted by the writers in an exceptionally tight warehouse, bagged peanuts retained so much of the gas that it was unsafe for workmen to enter the warehouse until it had been aired for 5 days.

VAULT FUMIGATION FOR NUTS

Nuts are usually fumigated in atmospheric vaults or vacuum tanks before they leave the factory or go from the storage warehouse to the factory. A 1,000-cubic-foot atmospheric vault will hold about half a carload of bagged nuts, such as peanuts—about two hundred and fifty 100-pound bags of shelled peanuts or 125 such bags of peanuts in the shell.

A dosage of 3 pounds of ethylene oxide or 25 pounds of the ethylene oxide-carbon dioxide mixture per 1,000 cubic feet of space, with an exposure of from 20 to 24 hours, will give excellent results at a cost of from 1 to 3 cents per 100-pound bag, including labor charges.

Hydrocyanic acid can also be used for fumigating nuts in atmospheric vaults, although it is not so popular for this purpose as ethylene oxide. A dosage of one-half pound of liquid hydrocyanic acid or its equivalent is required for each 1,000 cubic feet of space.

VACUUM FUMIGATION FOR NUT MEATS

For the vacuum fumigation of nuts the ethylene oxide-carbon dioxide mixture is excellent. A dosage of 30 pounds per 1,000 cubic

feet for a period of from 1 to 2 hours gives satisfactory results at a cost of from 3½ to 4 cents per 100 pounds of nuts. A mixture of carbon disulphide and carbon dioxide has been used in the vacuum treatment of nuts, but owing to the need for special equipment for applying it safely and to the fact that it is unsuitable for the treatment of pecans, Brazil nuts, and cashews, it is not recommended.

FUMIGATION SCHEDULE FOR CANDY FACTORIES

The adoption of a regular fumigation schedule would largely eliminate insect losses in the candy industry. Infested raw materials and returned goods constitute the main sources of infestation in the factory. Insects from these sources spread all over the factory and lay eggs on the finished product. These eggs hatch after the candy is packed and produce costly infestations in packages that leave the factory apparently in good condition.

Every candy factory should have a fumigation vault or a vacuum chamber, and all returned goods should be fumigated before they are admitted to the factory. All incoming raw materials that are susceptible to insect attack, such as nut meats, cocoa beans, farinaceous materials, dried fruits, milk powders, and chocolate, should be rigidly inspected on their arrival at the plant and, if infested or suspected of being infested, should be fumigated before being placed in the main storage sections. If possible, raw materials should be stored away from the main part of the factory, and in sections that are adapted for separate fumigation.

DOSAGES

Returned goods and raw materials other than nut meats can be fumigated in tight vaults with one of the following fumigants at the dosages indicated per 1,000 cubic feet: Ethylene oxide, 2 pounds; ethylene oxide-carbon dioxide mixture, 20 pounds; or liquid hydrocyanic acid or its equivalent, 8 ounces.

Large storage sections can best be fumigated with hydrocyanic acid at the rate of 8 ounces of liquid hydrocyanic acid or its equivalent per 1,000 cubic feet.

As a general precaution it is advisable to fumigate the entire factory at least once a year. For this purpose hydrocyanic acid should be used at the same rate as for the treatment of the large storage sections.

FURNITURE

Insect-infested furniture is usually fumigated in an atmospheric vault, although a vacuum vault can be used and is preferable in cases where infestation is due to wood-boring insects.

Hydrocyanic acid, ethylene oxide, ethylene oxide-carbon dioxide mixture, carbon disulphide, chloropicrin, carbon tetrachloride, and the ethylene dichloride-carbon tetrachloride mixture can all be used for the fumigation of furniture in atmospheric vaults.

Hydrocyanic acid and the ethylene dichloride-carbon tetrachloride mixture are used most commonly. A dosage of 8 ounces of liquid hydrocyanic acid or its equivalent, or of 14 pounds of ethylene dichloride-carbon tetrachloride mixture, per 1,000 cubic feet of space, for a period of 12 to 24 hours will give satisfactory results unless

wood borers are involved, when the exposure should be at least 48 hours. If any of the other fumigants are used, the following dosages should be applied per 1,000 cubic feet of space: Ethylene oxide, 2 pounds; ethylene oxide-carbon dioxide mixture, 20 pounds; carbon disulphide, 5 pounds; chloropicrin, 1 pound; or carbon tetrachloride, 30 pounds.

FURS AND GARMENTS

The protection of furs and fur garments in storage by fumigation instead of cold storage is becoming more and more common. The method consists merely in storing fur garments in tight rooms (fig. 35) that are so arranged that they can be fumigated regularly. The fur garments are fumigated in a small fumigation vault (figs. 2 and 28) before being placed in the storage rooms (fig. 36).

CONSTRUCTION OF STORAGE ROOMS

The large storage rooms may be of any type of construction that is sufficiently tight for fumigation purposes. Usually they are of concrete or of hollow tile covered with Keen's cement. The surface should be finished with 2 or 3 coats of gas-resistant paint. Large, shallow evaporating pans are fastened along the walls near the ceiling. These pans are connected by pipes to the storage tank (fig. 37) containing the fumigant. If ethylene dichloride-carbon tetrachloride mixture is used as the fumigant, it can be run into the evaporating pans by gravity or by the use of a small compressor. If ethylene oxide-carbon dioxide or methyl formate-carbon dioxide mixture is to be used, the evaporating pans are unnecessary, and a piping system with one or several spray nozzles or cones should be used instead. The cylinders containing one of these mixtures with carbon dioxide are connected to the piping system outside of the room (fig. 27), and the fumigant is applied by merely opening the valve on the cylinders and allowing the required poundage to be discharged.

The door of the storage room is usually of the safe or refrigerator type, well gasketed so that it will be airtight. An adequate ventilating system must be installed, so that the gas can be quickly removed after the fumigation. As in the case of small fumigation vaults, the ventilating stack should extend well outside the building.

In cold climates there should be some means of heating the storage room to at least 70° F. during the fumigation.

If it is necessary to enter the storage room while it is under fumigation, the operator should wear a gas mask equipped with a canister designed for protection against the particular gas that is being used and should remain in the room only long enough to obtain the garment needed.

DOSAGES

For the fumigation of the large storage sections a dosage of 14 pounds of the ethylene dichloride-carbon tetrachloride mixture, 20 pounds of ethylene oxide-carbon dioxide mixture, or 28 pounds of a methyl formate-carbon dioxide mixture, per 1,000 cubic feet of space and an exposure of at least 48 hours should be used.

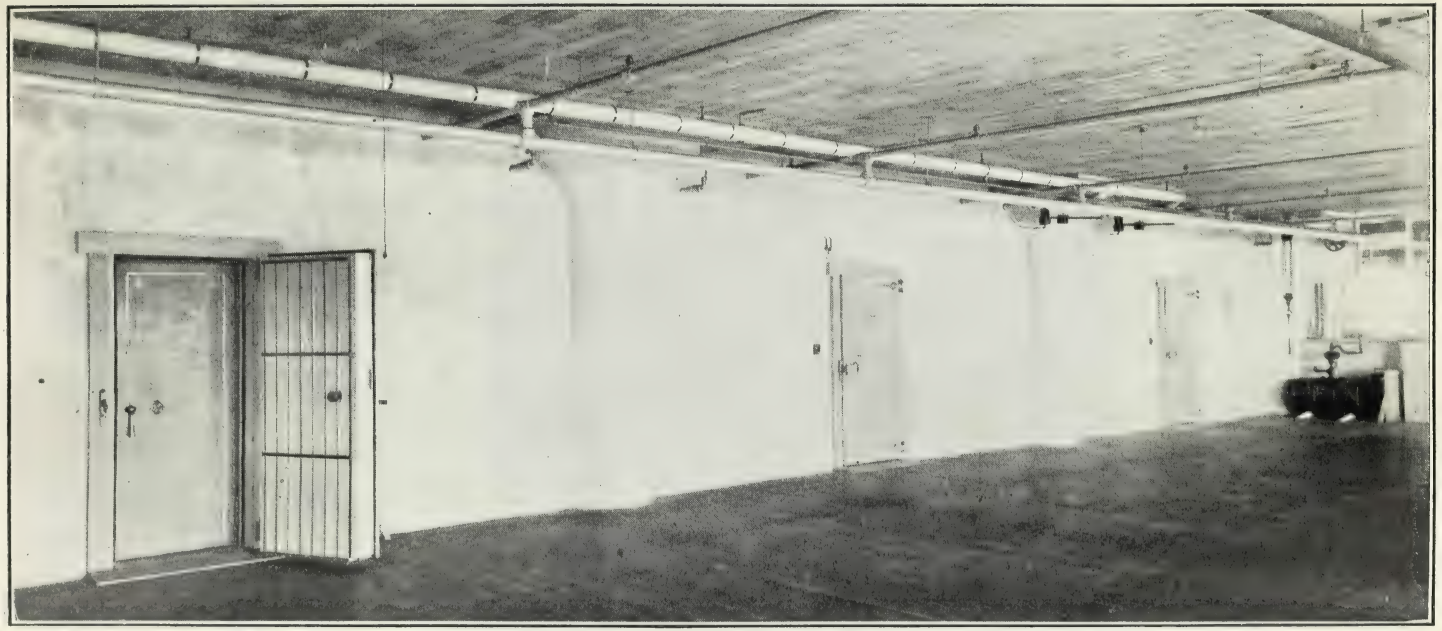

FIGURE 35.—Battery of three large fumigable fur-storage vaults constructed in a modern concrete building, equipped with burglar alarms, devices for regulation of temperature and humidity, and for introducing and taking out the fumigant. At right on warehouse floor, note storage for fumigant and pump for forcing fumigant to any room desired. These rooms have been operated successfully in southern California for nearly 10 years.

For the preliminary fumigation of fur garments in small vaults the same fumigants and the same dosages recommended for the large storage sections can be used, although an exposure of 12 to 24 hours is sufficient.

EFFECT OF FUMIGATION ON FURS

Fur garments appear to be in no way affected by the vapors of the fumigants recommended, and dry storage has no deleterious effect upon the furs. A few instances of change in color of furs stored in fumigable storage have been reported, but in no case has this been clearly shown to be the result of fumigation. Thousands of dollars' worth of furs are being stored annually in fumigable storages throughout the country, to the satisfaction of all concerned.

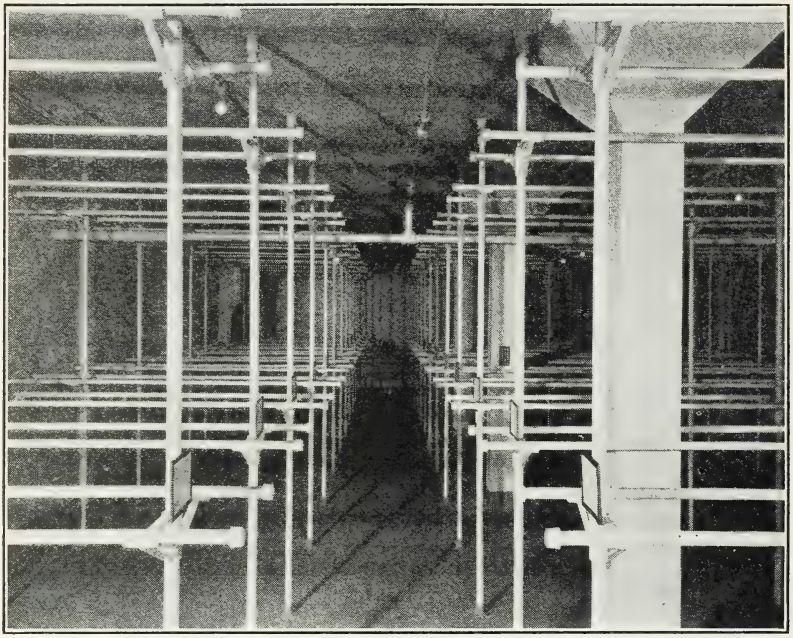

FIGURE 36.—Interior of fur-storage vault with racks installed for holding garments in best possible position for ready access and effective fumigation.

RUGS AND TAPESTRIES

Rugs and tapestries in storage can be protected by the same methods and equipment that are recommended for the storage of furs. Many firms, however, prefer to use naphthalene flakes or paradichlorobenzene crystals in place of liquid fumigants. On exposure to air at ordinary room temperatures, both these solid fumigants give off a heavy vapor, which gradually permeates the atmosphere of the storage room. If a saturated atmosphere of either of these materials is maintained in the storage room, adequate protection from insects can be obtained (fig. 38).

At a temperature of 77° F., 8 ounces of paradichlorobenzene or 0.64 ounce of naphthalene is required to saturate the atmosphere in 1,000 cubic feet of space. Under ordinary storage conditions, however, it is advisable to use an excess of these fumigants in order to counteract losses by absorption and leakage and to insure a continuously saturated atmosphere.

When no attempt is made to hasten evaporation by the application of heat, the vapors of naphthalene and paradichlorobenzene are not so quickly toxic to insects as are the liquid fumigants. Their chief value lies in the continuous protection that they afford. Since vapors are evolved but slowly from the crystals, one application may last for several months.

Aside from having an irritating effect upon the eyes, the vapors of naphthalene and paradichlorobenzene are apparently not injurious to man unless inhaled in strong concentrations for an extended period.

Paradichlorobenzene crystals can be purchased for from 16 to 60 cents per pound in small lots. Naphthalene flakes are quoted at 2½ to 10 cents per pound.

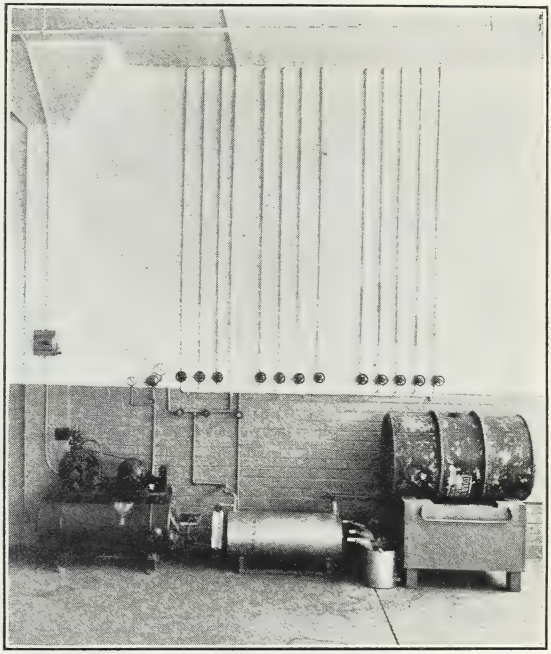

FIGURE 37.—Exterior view of commercial fur-storage vault equipped for fumigation with ethylene dichloride-carbon tetrachloride mixture. Note storage drum at right, pump at left, and pressure tank in center connected with various fumigating vaults, not shown, by pipe lines on wall.

DRIED FRUIT

Dried fruit is very susceptible to insect attack and must be protected from infestation at all times. Growers and packers usually find it necessary to fumigate dried fruit before it is stored, and for this purpose should equip themselves with fumigation chambers or fumigable storage bins (fig. 3). The fumigation of dried fruits under rubberized tarpaulins is reasonably effective. The fruit can be fumigated and then placed in an insect-tight storage section, or it can be placed directly in storage bins that are so constructed that they can be fumigated from time to time as needed. Any type of construction that is gastight is suitable for storage bins.

On ranches (figs. 29 and 30), where the fire hazard can be guarded against, carbon disulphide can be used. It is both cheap and effective. A dosage of 20 pounds per 1,000 cubic feet of space and an exposure of 24 hours at a temperature of 70° F. or higher will give

satisfactory results. Chloropicrin is often used as a fumigant in special farm storages.

In packing houses or storage sections where fumigation chambers or fumigable storage bins are not isolated, a fumigant that does not have the fire hazard of carbon disulphide is desirable. In such circumstances ethylene oxide or a mixture of ethylene oxide and carbon dioxide can be used. Ethylene oxide at the rate of 2 pounds, or the ethylene oxide-carbon dioxide mixture at the rate of 20 pounds, per 1,000 cubic feet of space should be for a period of 24 hours.

Hydrocyanic acid can also be used in airtight vaults at the rate of 1 pound of liquid hydrocyanic acid or its equivalent per 1,000 cubic feet. Hydrocyanic acid gas is absorbed in considerable quantities by dried fruit, but is quickly given off after the fruit is aerated.

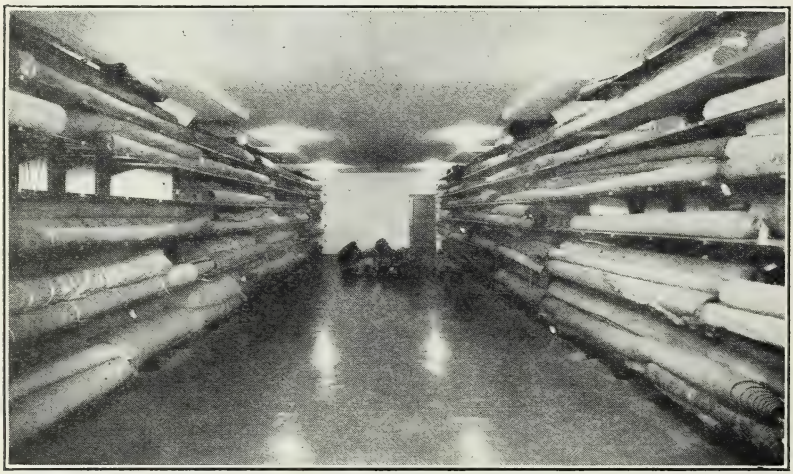

FIGURE 38.—Rug-storage vault in which rugs are protected against fabric pests by vapors of paradichlorobenzene or flake naphthalene.

TREATING THE FINISHED PRODUCT

It is sometimes desirable to fumigate the finished package prior to shipping it from the packing plant. For this purpose a fumigation room or a vacuum tank is necessary. If a fumigation chamber is used, the fumigants and dosages recommended for the raw products can be used. If vacuum fumigation is resorted to, excellent results can be obtained with a dosage of 30 pounds of the ethylene oxide-carbon dioxide mixture per 1,000 cubic feet for a period of from 1 to 2 hours.

INFESTATIONS IN WAREHOUSES

Infestations that develop in storage warehouses can be handled by fumigating the infested fruit in a fumigation chamber or vacuum tank or by fumigating the entire storage section with hydrocyanic acid. If the entire storage section is fumigated, a dosage of from 8 to 16 ounces of liquid hydrocyanic acid or its equivalent per 1,000 cubic feet of space should be used for a period of 24 hours. The dosage will depend on the tightness of the storage section and the quantity of fruit in storage.

CURED MEATS AND CHEESES

Infestation of cured meats and cheeses by mites, ham beetles, or skippers frequently makes fumigation necessary. Meat-storage houses that are reasonably tight can usually be successfully fumigated with hydrocyanic acid at the rate of 1 pound of liquid hydrocyanic acid or its equivalent per 1,000 cubic feet for a period of 24 hours. Such treatment does not injure the meats, but if the infestation has penetrated deeply into the meat, it is difficult to get a perfect kill. The Federal meat-inspection regulations [5] require that permission for each fumigation be obtained from the Federal meat inspector.

Cheeses that are protected by an unbroken layer of paraffin can be safely fumigated with hydrocyanic acid, but, owing to the danger of

FIGURE 39.—Interior of tobacco storage with tobacco stored in hogsheads.

their absorbing large quantities of the gas, unprotected cheeses should be removed from a warehouse that is to be fumigated.

For the treatment of small quantities of cured meats or cheeses, a fumigation vault or other tight container is recommended. Carbon disulphide at the rate of 10 pounds, ethylene oxide at the rate of 2 pounds, or the ethylene oxide-carbon dioxide mixture at the rate of 20 pounds, per 1,000 cubic feet of space can be used for a period of 24 hours.

STORED TOBACCO

Tobacco that is held in storage (figs. 39 and 40) often becomes infested with the tobacco beetle (*Lasioderma serricorne* Fab.) or the tobacco moth (*Ephestia elutella* Hbn.). If the infested tobacco is

[5] U. S. Department of Agriculture, Bureau of Animal Industry, Service and Regulatory Announcements, January 1921, p. 3, and August 1927, p. 62.

held in closed storage, fumigation with hydrocyanic acid gas is the most effective means of preventing further loss from insect attack. One fumigation a season should be sufficient to control the tobacco beetle unless additional infested stocks are moved into the storage section after the fumigation. If the tobacco moth is present, it will probably be necessary to fumigate 2 or 3 times during a season. Where only one fumigation is given, a dosage of 1 pound of liquid hydrocyanic acid or its equivalent should be used per 1,000 cubic feet of space, but if more than one is to be given, a dosage of 8 ounces is sufficient. If possible, an exposure of from 48 to 72 hours should be given in each instance.

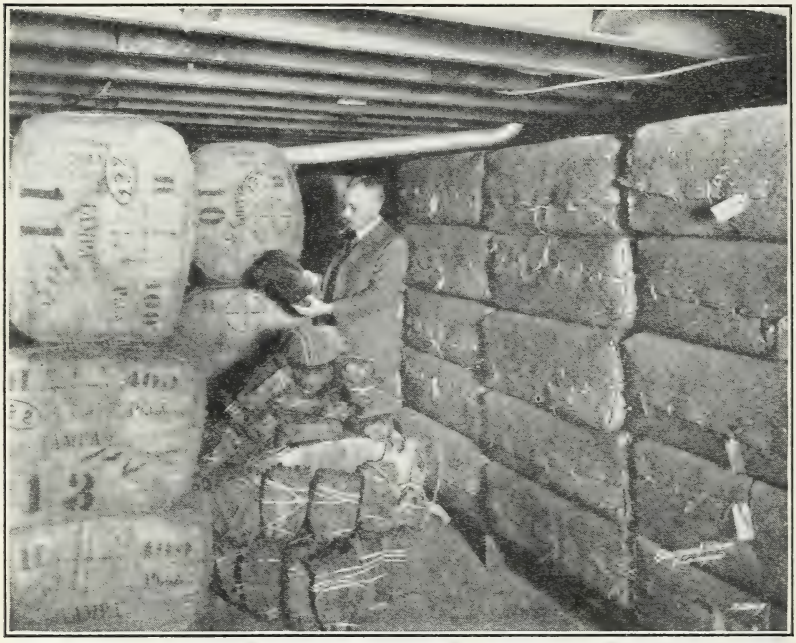

FIGURE 40.—Tobacco in bales and stacked as closely as shown here cannot be fumigated satisfactorily by ordinary atmospheric fumigation. The bales should either be more loosely stacked or removed to vacuum chambers for fumigation.

For the fumigation of tobacco factories a dosage of 8 ounces of liquid hydrocyanic acid or its equivalent per 1,000 cubic feet for a period of 24 hours is sufficient.

In order to keep down infestation in tobacco factories, many firms make a practice of fumigating all incoming tobacco in airtight vaults. For this purpose hydrocyanic acid in a dosage of 10 ounces of liquid hydrocyanic acid or its equivalent, ethylene oxide at the rate of 2 pounds, ethylene oxide-carbon dioxide mixture at 20 pounds, or carbon disulphide at 10 pounds, per 1,000 cubic feet of space should be used for a period of from 48 to 72 hours. Carbon disulphide should not be used unless the vault is isolated from the rest of the buildings and the fire hazard can be controlled. The fumigation of an entire tobacco warehouse with carbon disulphide is a dangerous procedure and is not recommended.

Vacuum fumigation is sometimes used for the treatment of tightly baled tobacco (figs. 31 and 32). In order to penetrate the bales and to insure a quick kill, large quantities of fumigant are necessary. A dosage of from 3 to 5 pounds of liquid hydrocyanic acid or 45 pounds of the ethylene oxide-carbon dioxide mixture per 1,000 cubic feet is required for a 2½-hour exposure.

FLOUR

For controlling insects in flour mills and reducing insect damage to milled products, some form of fumigation is usually practiced. Many millers are satisfied to fumigate their mills once a year, while others find it profitable to fumigate several times a year. One thorough fumigation a year will usually control the Mediterranean flour moth (*Ephestia kuehniella* Zell.), but the various flour beetles are not so easily controlled.

PREPARING THE MILL FOR FUMIGATION

On account of the milling machinery the preparation of a flour mill for fumigation is more of a problem than is the case in the ordinary building. Instead of each floor being treated separately, the whole building is considered as a unit. In addition to the ordinary procedure for preparing a building for fumigation, the directions suggested by Dean and Schenk [6] should be followed:

Before Stopping Mill

1. Shut off feed (wheat) at mixing bin.
2. Continue running all machinery until material is emptied from spouts, elevators, conveyors, rolls, sifters, reels, purifiers, feed duster, suction trunking, and dust collectors.
3. Meanwhile, hammer elevator legs, machinery, frames, tubular dust collectors, and spouts with a rubber mallet or other device which will not bruise or injure the equipment.

After Stopping Mill

1. Open all machines, elevator boots, conveyor boxes, and flour bins.
2. Remove covers of all conveyors, making certain that all dead-end spaces are readily accessible.
3. Thoroughly clean all conveyors, including dead-end spaces.
4. Clean out accumulations from bottom section of the bran duster.
5. Clean all elevator belting that may be webbed; drag spouts of same.
6. Remove the adjustable feed gage above grinding rolls and clean out accumulations above rolls and feeders.
7. Examine tubular dust collectors and clean out all accumulations.
8. Clean out suction trunks, conveyors, and dust-collector systems.
9. Open dust-collector trap boxes, main trunks, and hand openings.
10. Loosen all sifter doors to permit entrance of gas during fumigation.
11. Leave every machine open; also all hand openings to spouts, elevator legs, etc.
12. Remove and burn all infested materials accumulated in cleaning the mill.
13. All infested lots of flour and other milled products should be removed (or reconditioned) before cleaning the mill. These products should not be returned.
14. If the above procedure is followed, no accumulation of more than 1 inch in depth will be present in the mill.
15. Special attention should be given to the cleaning of the "dead" spouts and "dead" spaces in corners of spouts and machines.
16. Remove all bags and other materials used to plug spouts.

---

[6] Dean, G. A., and Schenk, G. The control of stored grain and flour mill insects. Fourth Internatl. Cong. Ent. Trans. (1928) 2: 217–218, illus. 1929.

CHOICE OF FUMIGANT

Chloropicrin and hydrocyanic acid are the two fumigants that can be used successfully for mill fumigation. Hydrocyanic acid is more popular and gives more consistent results.

HYDROCYANIC ACID GAS FOR MILL FUMIGATION

In general, a dosage of 8 ounces of liquid hydrocyanic acid or its equivalent per 1,000 cubic feet of space has been found most satisfactory for flour-mill fumigation. All the methods that have been described for generating this gas may be used with good results. For the miller who does his own fumigating, the pot or barrel method is safer and cheaper, and therefore more desirable, although the hot gas produced by this method is likely to escape from the building faster than the cold gas produced by other methods.

Professional fumigators generally use liquid hydrocyanic acid. An initial dosage of 4 ounces per 1,000 cubic feet of space, followed by two dosages of 2 ounces at intervals of 2 hours, is sometimes used, though it is doubtful whether the results are any better than when the entire dosage is applied at one time.

A combination of the liquid hydrocyanic acid and the calcium cyanide (40 to 50 percent $Ca(CN)_2$) methods has also been used with success. An initial high concentration is obtained from the liquid hydrocyanic acid, and this is maintained for from 4 to 6 hours by the gas that is slowly evolved from the calcium cyanide. Four ounces of liquid hydrocyanic acid and 1 pound of calcium cyanide per 1,000 cubic feet of space produce approximately the same quantity of gas as 8 ounces of liquid hydrocyanic acid, and this is a good combination to use. The calcium cyanide is applied first, and after all the fumigators have left and closed the building the liquid hydrocyanic acid is forced in through the piping system from the loading platform.

Distribution of the Fumigant

In general the gas should be equally distributed on all floors of a mill. If, however, the floors are not well separated one from the other on account of belt openings, poorly fitting doors, floors, elevator openings, etc., the gas will tend to concentrate on the top floors; hence the dosage on the lower floors should be somewhat heavier. Floors that contain more machinery than others should also receive a heavier dosage.

Length of Exposure

Since it is difficult to hold a killing concentration of the gas in the average mill for more than a few hours, an exposure of from 18 to 20 hours is all that is practical.

CHLOROPICRIN AS A MILL FUMIGANT

Under favorable conditions chloropicrin at the rate of 1 pound per 1,000 cubic feet of space is a satisfactory flour-mill fumigant. It should be used only in a tight building and when the temperature is above 70° F.

CORRECTION

Circular 369, United States Department of Agriculture, "Industrial Fumigation against Insects": Page 49, line 1, substitute "page 24" for "page 48".

As indicated on page 48, there are several ways of applying the gas, but the most effective method is to introduce the entire dosage for the building into the machinery itself. If the machinery is run for a short time while the gas is being applied, the vapor will be distributed to all parts of the mill.

The vapors of chloropicrin have a deleterious effect on the baking qualities of flour, but flours fumigated with chloropicrin show complete recovery after being properly aerated. After a fumigation with chloropicrin, it is advisable to lay aside the first few bags of flour that come through the mill and feed them back slowly into the mill. In this way the chloropicrin is soon dissipated.

LOCAL FUMIGATION

Since insect infestation in a flour mill is confined largely to the machinery, many millers prefer to fumigate the machinery alone instead of the entire mill. The cubic content of the machinery being only a fraction of that of the mill, the miller can afford to fumigate more often. With a little sealing and plugging, each machine can be separated from the others and fumigated when necessary. Instead of only on week-ends, this type of fumigation can be utilized any night after the mill is shut down. Hydrocyanic acid, chloropicrin, ethylene dichloride-carbon tetrachloride mixture, or the ethylene oxide-carbon dioxide mixture can be used. The machinery can be specially piped and the fumigants sprayed in through nozzles, or the liquids can be applied by hand. Two or three times the ordinary dosage for general mill fumigation can be used in the machinery without great expense.

As in regular mill fumigations, the operator should wear a gas mask when applying the fumigant and also when airing out the machinery the following morning.

FUMIGATION OF FLOUR WAREHOUSES

It is often desirable to fumigate warehouses containing flour, feed, or other cereal products. A complete kill cannot always be obtained, however, since fumigants will not penetrate more than 1 or 2 inches into bagged flour. Fortunately, insect infestation of bagged flours is usually near the surface, and under favorable conditions the kill is good enough to make fumigation well worth while. A dosage of 8 ounces of liquid hydrocyanic acid or its equivalent per 1,000 cubic feet of space for from 17 to 24 hours should be used.

VAULT FUMIGATION FOR FLOUR OR CEREAL MILL

For the treatment of used bags, returned goods, or small lots of infested flour or cereals, a fumigation vault is almost essential. The vault can be of any of the types discussed on page 28. If possible, it should be located in a building separate from the main mill, so that used bags or returned goods can be fumigated before being taken into the main building.

Used bags can be fumigated successfully with any of the fumigants recommended for vault fumigation, and at the same dosages.

Bagged flour is fumigated with difficulty owing to the great absorption of the gas by the outer layers of flour. Schenk [7] found that satisfactory results could be obtained with 140-pound bags of flour by using a dosage of 3 pounds of liquid hydrocyanic acid per 1,000 cubic feet of space for 24 hours at 70° F. The bags should be separated from one another in the vault by means of racks.

For packaged cereals a dosage of 2 pounds of liquid hydrocyanic acid or its equivalent, or 30 pounds of the ethylene oxide-carbon dioxide mixture, per 1,000 cubic feet of space should be used for a period of 24 hours.

SAFEGUARDS TO BE EMPLOYED IN FUMIGATION WORK

In all fumigation work the person in charge should not only acquaint himself with the dangers involved, but should bring his assistants together and explain to them the need for caution, and what should be done in case difficulty arises. He should know the first-aid recommendations issued by the manufacturers of the particular fumigant he is about to use. He should employ only men known to be dependable. Members of the fumigating crew should be in good physical condition, with minds alert so that they can act calmly and rapidly and work together according to a prepared and rehearsed plan of procedure. They should abstain from the use of intoxicants. They should take no chances.

All persons except fumigators should leave the building.—When an entire building, or any floor, is to be fumigated, all persons in the entire building should be notified in advance and told that they must leave the building between certain specified hours. In large establishments the owners should be held responsible for keeping persons out of a building unless they have a definite agreement with the fumigator that he assume all responsibility connected with the safe conduct of the fumigation.

It is not always necessary, or desirable, for persons to leave certain buildings while vaults or similar limited areas are under fumigation. Much depends upon the fumigant used, the type of building, and the methods employed for ventilation. The informed fumigator is in a position to determine what action is necessary. Many routine vault fumigations are conducted daily in congested city areas without danger to human life.

Danger signs should be posted.—Placards calling attention to the fact that a fumigation is being conducted and warning persons to keep out should be posted on all outside doors of the building.

Guards for buildings are desirable.—Guards should be stationed outside buildings to make certain that they are not heedlessly entered while being fumigated with a dangerous vapor.

Gas masks should be available.—Gas masks should always be worn during fumigation with hydrocyanic acid gas, chloropicrin, or any other quickly fatal fumigant. Ethylene oxide, methyl formate, ethylene dichloride, carbon disulphide, and carbon tetrachloride, either alone or in the combinations usually recommended for fumigation work, are regarded as only slightly toxic to man as he ordi-

[7] Private communication.

narily comes in contact with their vapors in fumigation work, and gas masks are not usually employed unless the fumigators must remain exposed to their vapors for long periods.

Continued exposure to any fumigant useful in insect control will prove fatal to man. Every fumigator should therefore obtain information from the manufacturer of the fumigant he intends to use, as well as profit from his own experience, concerning what is a safe attitude to take toward the use of gas masks. Firms selling fumigants should be consulted regarding suitable gas masks for protection from their products, or information can be had from the United States Department of Agriculture.

Never assume that a gas mask will protect.—Obtain definite assurance that it is equipped with a canister of chemicals prepared to neutralize the vapor or vapors to be used. Attach a fresh, unused canister to the mask unless the exact history of the one already attached is known. Canisters for gas masks cost only about $2 each. There is no need to take chances. Do not permit familiarity with any dangerous fumigant to lead to criminal carelessness.

FIRST AID FOR POISONING FROM HYDROCYANIC ACID GAS

Inhaling hydrocyanic acid gas or absorbing it through the skin is dangerous and must be avoided. If it is absorbed by the system, prompt steps to counteract its action must be taken. Any one or several of the following symptoms may indicate poisoning:

(1) Weakness or palpitation of the heart.
(2) Headache or dizziness.
(3) Rushing of blood to the head.
(4) Weakness or heavy feeling in the limbs and joints.
(5) Nausea and vomiting.
(6) Difficulty in breathing, contraction of the chest.
(7) Fainting and unconsciousness.

If a fumigator feels that he is being affected, he should indicate this to his coworker and together they should leave the building and remove their masks in the fresh air. This makes certain that the affected person reaches the fresh air safely. Men have been known to start for the exit only to become unconscious en route, and if this happens the assistance of the coworker is necessary. If on reaching the outside he is found to be only slightly affected, he can be left alone until he feels fully recovered, while the coworker, with another of the fumigating crew, returns to complete the work.

If, however, a fumigator has difficulty in walking, becomes unconscious, or is appreciably affected in other ways, he should be hastily removed from the building to the open air and immediate provision made to keep him warm. Then—

If the patient is conscious, insist on vigorous exercise by walking (with another person at his side), preferably against the wind if a breeze is stirring, and have him inhale ammonia vapor from a bottle of ammonium carbonate. Do not allow him to sit down and rest, or go to sleep. Do not give hypodermic injections. Do not give alcoholic stimulants. Do not give liquid by mouth unless he is fully conscious. Do not allow him to return to work until he has fully recovered from the effects of the gas.

If he has fainted, cause him to inhale ammonia vapor and induce respiration by vigorous movements of the arms, continuing until full consciousness returns. If he is completely unconscious, loosen the clothing, bathe the face with cold water, and, if breathing has ceased, begin artificial respiration at once, using the Shaefer prone-pressure method (see below).

If he is affected by absorption of gas through the skin, remove clothing immediately, particularly if liquid hydrocyanic acid has been spilled on it, or it is damp from perspiration or other cause. If the patient is breathing, have him inhale ammonia vapors and, where recovery is delayed and the patient is fully conscious, give 10 drops of aromatic spirits of ammonia in one-third glassful of water. If breathing has ceased, begin artificial respiration at once, using the Shaefer prone-pressure method; stop as soon as the patient begins to breathe voluntarily.

If the patient does not respond immediately to first aid, call a physician. Never rush an unconscious person to the hospital until first-aid measures have been applied or until a physician arrives. If possible, when the patient is unconscious, a mixture of oxygen and 5 percent carbon dioxide should be administered for 20 to 30 minutes through a specially designed inhalator. Such equipment, however, is seldom available until assistance has been obtained.

SHAEFER PRONE-PRESSURE METHOD OF ARTIFICIAL RESPIRATION [8]

1. Lay the patient on his belly with his face to one side so that his nose and mouth are free for breathing. Place one of his arms straight out beyond his head and the other under his head, with both hands flat and palms down.

2. Kneel, straddle one of the patient's thighs, and face his head; rest the palms of your hands on his loins with your thumbs along the index fingers and with fingers spread over lowest or floating ribs.

3. With your arms held straight, swing forward slowly for about 3 seconds so that the weight of your body is gradually, not violently, brought to bear upon the patient.

4. Then, leaving your hands in place, swing backward slowly so as to remove the pressure, thus returning to the position noted in paragraph 2. Then remove the hands to allow the ribs to expand quickly, filling the lungs with air. Swing slowly backward to upright position, thus relieving the muscles of the back.

5. Repeat deliberately 12 times per minute, swinging forward and backward without interruption until natural breathing is restored or until the doctor arrives.

Artificial respiration should be continued 3 to 4 hours if necessary.

Breathing may also be stimulated by sharply striking the soles of the feet with a stick or shoes. This so-called "hot-footing" is done every 2 or 3 minutes during artificial respiration.

Keep the patient warm by whatever means are available.

[8] These directions are summarized from those given by other authors. Complete authentic information concerning this method can be obtained from the U. S. Public Health Service, Washington, D. C.

U. S. GOVERNMENT PRINTING OFFICE: 1935

For sale by the Superintendent of Documents, Washington, D. C. - - - - - - Price 5 cents